APPLICATION OF CONVENTIONAL MINING TECHNIQUES TO UNDERGROUND OIL SANDS MINING

Submitted by

COMINCO ENGINEERING SERVICES LTD.
AND
NORWEST RESOURCE CONSULTANTS LTD.

Cominco Engineering Services Ltd. — a subsidiary of Cominco

Norwest Resource Consultants Ltd.

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada.

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Canmet Project Number	:	**202802**
Canmet Scientific Authority	:	**Mr. G. ZAHARY**

August 1985

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Cominco Engineering Services Ltd. a subsidiary of Cominco

Norwest Resource Consultants Ltd.

August 20, 1985

CANMET
380-4500 16 Avenue, N.W.
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Calgary, Alberta
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Attention: Mr. G. Zahary

Dear Mr. Zahary,

On behalf of the joint venture between Cominco Engineering Services Ltd. and Norwest Resource Consultants Ltd. we have pleasure in submitting ten copies of our report on "Application of Conventional Mining Techniques To Underground Oil Sands Mining". Five copies of the Executive Summary are also enclosed.

We hope that this assignment, which we have found both interesting and challenging, will be the first step in an investigation into the use of the concepts we have called the "Mining Enhanced In Situ System". As we have concluded in our report the system has potential for improving recovery of bitumen from oil sands reserves too deep for surface mining. Given the importance to Canada of this vast and relatively untapped resource we believe a significant effort is more than justified.

Yours very sincerely,

H.G. Stephenson, P. Eng.
President
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23SQ. 23440-4-9198

Prepared For: Department of Supply and Services

Prepared By: Norwest Resource Consultants Ltd.
and
Cominco Engineering Services Ltd.

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EXECUTIVE SUMMARY

1. BACKGROUND

Canadian oil sands deposits contain vast reserves of bitumen of which only a very small percentage is believed to be recoverable by surface mining. In situ methods hold out most promise for recovery of bitumen from the deeper reserves. Unfortunately, especially in the Athabasca field, reservoir permeability is extremely low and conventional in situ processes recover a very small percentage of bitumen. It is thought that conventional underground mining techniques may be applied to increase permeability and to improve or assist the recovery of bitumen by in situ processes.

2. CONCEPTS

There are three basic concepts for applying conventional underground mining techniques to assist recovery of bitumen from oil sand.

- The first concept utilizes tunnels to place in situ equipment close to the reservoir. This is known as the Shaft And Tunnel Access Concept, or SATAC.
- The second involves extraction of a limited fraction of the oil sands to improve the permeability of the reservoir for in situ processes. This has been described as a Mining Enhanced In Situ Scheme
- The third concept involves bulk mining of oilsand by underground operations and processing on the surface.

The SATAC concept is already being intensively investigated by AOSTRA. This report examines use of the second and third options to provide a means of recovering bitumen from those reserves which are too deep for surface mining.

3. MINING ENHANCED IN SITU SYSTEM

It is felt that partial excavation of deep oil sand, resulting in controlled caving and fracturing of the reservoir prior to the use of in situ methods, is likely to enhance recovery of bitumen. This Mining Enhancement In Situ Technique may improve drainage of heated bitumen by fracturing horizontal barriers of clay or siltstone and causing bulking or expansion of oil sand. This in turn would encourage the flow of steam or other agents, the transfer of heat from injection wells and the drainage of bitumen to production wells.

If this concept is to be evaluated it is necessary as a first step to conduct simple experiments investigating the excavation of oil sand and the behaviour of the beds around such an excavation.

4. BULK MINING

The consultants believe that it is highly unlikely that bulk extraction of oil sand using conventional underground methods will be economically or operationally practicable in the forseeable future.

5. PROBLEMS

There has been no direct experience of underground mining at depth in the Alberta oil sands. Problems likely to be encountered, some of which are unique to oil sands, include;

- The exsolution of gases resulting in destabilization of the oil sands and subsequent difficulty in supporting faces.
- The abrasive effect of sand on mining equipment.
- Difficulties caused by the sticky nature of the material.
- Difficulties caused by drainage of liquid bitumen into the workings.
- The absence of reliable detailed information on the quantity of gas expected to be given off by exposed faces in oil sand.

6. THE UNDERGROUND TEST FACILITY

The AOSTRA Underground Test Facility (UTF), now under construction, will provide an opportunity for research into the application of underground mining techniques in oil sand, providing AOSTRA is prepared to allow the facility to be used for this purpose. Experiments which are described later could be most conveniently and economically be carried out from the UTF.

7. UNDERGROUND OIL MINING

Ten other projects or countries are identified where underground mining operations are currently used to assist in the recovery of oil from deep reservoirs.

8. TECHNIQUES FOR MINING ENHANCEMENT

Three techniques for applying the Mining Enhanced In Situ System are discussed. These are:

- Blasting to induce fractures in the oil sand.
- Induced subsidence in oil sand by extraction of the strata below the reservoir.
- Partial extraction of oil sand by mining.

Of these, the last is considered to have the greatest potential.

9. EXPERIMENTAL PROGRAM

A simple but vital experimental program has been outlined to provide the basic information required as a first step in evaluating the Mining Enhanced In Situ System. Key areas to be examined include:

- Gas exsolution and rate of gas in-flows.

- In situ strength of oil sand.
- Porosity and permeability enhancement.
- Equipment design.

The program includes three discrete experiments in two phases.

Phase I is divided into two parts. Phase IA includes excavation of an opening into the oil sands from a tunnel in the Devonian limestone and investigation of the caving characteristics of the sand. Phase IB would involve extension of this caved area by blasting, to improve the permeability of the reservoir over a larger area. Phase II involves tunneling in the oil sands.

Phase IA would involve the drivage of tunnels in limestone to a point a safe distance from the facility access tunnels and shafts, and 8 m below the base of the oil sands. A drawhole would then be developed by drilling and blasting in limestone. The tendency of the oil sand to cave and flow would be observed as the drawhole is widened.

Phase IB would involve drilling blastholes from the tunnel in limestone in a fan pattern around the caved area. After blasting, the effect on the caved area in the oil sands would be examined. Blasting would continue as appropriate to widen the test area.

Phase II would consist of driving a sloping tunnel up into the base of the oil sands from tunnels constructed in limestone during Phase I. After penetrating the reservoir the tunnel would be driven in oil sands to the area where Phase I testing was carried out, to observe at first hand the effects of the experiment. The report provides a description of the monitoring program during Phases I and II.

10. SCHEDULES

Phase I is expected to occupy a period of eighteen months, including the permitting procedure with the Provincial Government and negotiations with AOSTRA. Phase II is expected to take approximately twelve months. Monitoring of the experiment may continue after this period.

11. COSTS

Total costs are estimated as follows:

Phase I	$2,200,000
Phase II	1,600,000
User Fee (15%)	570,000
	$4,370,000

Almost 50% of the total costs are for tunnel drivages.

12. PATENTS

The report includes a list of 38 separate patents which cover areas related to the subject.

13. SAFETY AND HEALTH

A review of those aspects of safety and health which are of particular importance for the work proposed is provided. This covers:

- gas emissions and ventilation
- underground water inflows
- exposure to bitumen
- ground control in limestone and oil sand
- drilling and blasting

- hazard analysis
- operational procedures
- training and supervision

14. FURTHER RESEARCH

The report briefly describes further research work which could be initiated from the oil sands tunnel including:

- permeability enhancement in various ways including fracturing with explosives, hydraulic fracturing and caving
- steam injection trials
- hydraulic excavation

15. OPPORTUNITIES

The report presents an assessment of the challenge resulting from the problems of oil sands development, and of the opportunities for the mining industry which may develop as a consequence of this experiment.

16. CONCLUSIONS

It is concluded that the simple experiments proposed would provide valuable hard data on oil sands behavior which would permit a realistic assessment to be made of the potential inherent in Mining Enhanced In Situ Systems.

SOMMAIRE

1. DONNÉES DE BASE

Les gisements canadiens de sables pétrolifères contiennent une grande quantité de bitume dont un faible pourcentage seulement peut être récupéré par des méthodes d exploitation à ciel ouvert. Des procédés in situ semblemt les mieux appropriés pour la récupération du bitume dans les gisements souterrains. Malheureusement, surtout dans les" sables bitumeux de l' Athabasca", les reservoirs sont d' une perméabilité extrêmement faible et les procédés in situ classiques ne récupèrent qu' un infime pourcentage de bitume. Il est possible que les techniques classiques d' exploration souterraine pourraient y être appliquées afin d'y augmenter la permeabilité et d'améliorer ou de faciliter la récupération du bitume par des procédés in situ.

2. OPTIONS

Trois options fondamentales peuvent être considérées pour l'application des techniques classiques d'exploitation souterraine afin de faciliter la récupération du bitume dans les sables pétrolifères.

- La première option consiste en l'utilisation de tunnels pour installer l'équipement in situ près des réservoirs. Ce procédé est connu sous le nom de Concept d'accès par puits et tunne, (Shaft and Tunnel Access Concept - SATAC).
- La deuxième option consiste en l'extraction d'une petite quantité limitée de sables bitumeux dans le but d'augmenter la perméabilité due réservoir pour des procédés in situ. Ceci est connu sous le nom de Méthodes in situ de récupération assistée, (Mining Enhanced In Situ Scheme).
- La troisième option consiste en l'extraction complète des sables bitumeux au moyen d'une exploitation souterraine accompagnée d'une installation de traitement à la surface.

L'option SATAC est déjà l'objet d'une étude intensive par AOSTRA. La présente étude examine les deux autres options en vue de trouver un moyen de récupérer le bitume dans les gisements souterrains.

3. MÉTHODES IN SITU DE RÉCUPÉRATION ASSISTÉE

Il est peut-être possible d'accroître la récupération du bitume si l'emploi des procédés in situ est précédé d'une excavation partielle des gisements souterrains accompagné d'un effondrement contrôlé et d'une fracturation du réservoir. Cette "récupération assistée par des procédés in situ" pourrait améliorer le drainage du bitume chauffé en fracturant des barrières horizontales de grès ou de microgrès et en provoquant l'expansion des sables bitumeux (bulking). Ce procédé encouragerait tour à tour l'écoulement de la vapeur ou eutres agents, la transmission de la chaleur à partir des puits d'injection et le drainage du bitume jusqu'aux puits de production.

Afin d'évaluer cette option, il est nécessaire, à titre d'essai, de procéder à de simples expériences dans le but d'examiner l'excavation des sables bitumeux et les effets d'une telle excavation sur les couches avoisinantes.

4. EXPLOITATION "COMPLETE" (Bulk Mining)

Les ingénieurs-conseils croient qu'il est très improbable que l'extraction "complète" des sables pétrolifères suivant des méthodes classiques d'exploitation souterraine soit économiquement et fonctionnellement réalisable dans un avenir prévisible.

5. PROBLÈMES

L'exploitation minière faite à des profondeurs considérables n'a pas été expérimentee directement dans les sables petrolifères de l'Alberta. Parmi les problèmes susceptibles de se présenter, quelques uns uniques aux sables pétrolifères, il faut mentionner:

- l'exsolution de gaz provenant de la pertubation des sables bitumeux et les difficultés subséquentes quant au soutènement des tailles;
- l'effet abrasif du sable sur l'équipement minier;
- les difficultés causees par le caractère gluant du matériel;
- les difficultés occasionnées par le drainage du bitume liquide dans les chantiers d'exploration;
- l'absence d'information sûre et détaillée sur la quantité de gaz susceptible de se dégager des tailles exposées.

6. INSTALLATIONS POUR TESTS SOUTERRAINS

Les installations pour tests souterrains (Underground Test Facility - UTF) appartenant à AOSTRA et qui sont présentement sous construction, seront propices à la recherche sur l'application des techniques minières souterraines dans les sables pétrolifères, en autant que AOSTRA permettra l'utilisation de ces installations à cet effet. Ce serait l'endroit idéal où les expériences decrites plus loin dans cette étude pourraient être poursuivies d'une manière pratique et économique.

7. MINES SOUTERRAINES DES SABLES PÉTROLIFÈRES

Cette étude mentionne dix autres projets ou pays où l'on a recours à des exploitations minières souterraines pour la récupération assistée du pétrole.

8. TECHNIQUES DE RÉCUPÉRATION ASSISTÉE

Trois techniques in situ de récupération assistée sont considérées dans cette étude. Elles sont:

- le sautage en vue de fracturer la formation des gisements souterrains;
- l'effondrement provoqué dans les sables bitumeux par l'extraction de couches situées sous le réservoir;
- l'extraction partielle des sables bitumeux à partir d'une exploitation minière souterraine.

Parmi ces trois methodes, la dernière semble présenter le plus grand potential.

9. PROGRAMME EXPÉRIMENTAL

Cette étude comprend la description d'un programme simple mais important. Il a pour but l'obtention d'information de base nécessaire à l'évaluation des méthodes in situ de récupération assistée. Les points les plus importants à examiner sont;

- l'exsolution des gaz et le débit de l'arrivée des gaz;
- la résistance in situ des sables bitumeux;
- l'accroissement de la porosité et de la perméabilité;
- l'équipement approprié.

Ce programme comprend trois expériences simples divisées en deux phases.

La phase initiale comporte deux parties. La phase 1A comprend l'excavation d'un trou dans les sables bitumeux à partir d'un tunnel creusé dans le calcaire du Devonien et l'étude des traits caratéristiques de l'effondrement des sables. La phase 1B consisterait à étendre cet effondrement par sautage afin d'améliorer la perméabilité du réservoir sur une assez grande étendue. La phase II consiste à percer un tunnel à travers les sables pétroliferes.

La phase IA verrait le perçage de tunnels dans le calcaire jusqu'à un point situé à une distance sûre des installations d'accès aux puits et tunnels, et à 8 m sous la couche de base des sables bitumeux. Un trou d'extraction serait alors développé par forage et sautage dans le calcaire. La tendance des sables bitumeux à s'effondrer et à s'ecouler serait observée à mesure que le trou d'extraction s'élargirait.

La Phase IB consisterait à forer des trous de mines à partir d'un tunnel creusé dans le calcaire à la manière d'un éventail autour de la région effondrée. Les effets du sautage sur cette région effondrée des sables

bitumeux seraient ensuite examinés. Le sautage continuerait d'une mainère appropriée afin d'élargir la région sous étude.

La Phase II verrait le perçage d'un tunnel incliné jusqu'à la hauteur des sables bitumeux à partir des tunnels percés dans le calcaire à la phase I. Après avoir pénétre le réservoir, le tunnel continuerait dans les sables bitumeux jusqu'aux régions où les tests de la phase I auraient été poursuivis, et ce afin d'observer de première main les effets de ces expériences. Le présent rapport comporte une description du programme de surveillance qui serait effectue durant les phases I et II.

10. PLAN DE TRAVAIL

La phase I s'étendrait sur une période de dix-huit mois. Cela comprendait le temps nécessaire pour obtenir l'autorisation de procéder du gouvernement provincial et pour négocier avec AOSTRA. La phase II prendrait environ douze mois. La surveillance des expériences pourrait s'étendre au-delà de cette période.

11. FRAIS

Le total des frais est ainsi estimé:

Phase I	$2,200,200
Phase II	1,600,000
Frais d'utilisation (15%)	570,000
	$4,370,000

Le perçage des tunnels requiert près de 50% des frais.

12. BREVETS

Cette étude comprend une liste de 38 brevets distincts touchant des sujets relatifs à cette étude.

13. SÉCURITÉ ET SANTÉ

Dans cette étude, on passe aussi en revue certains aspects de sécurité et de santé pertinents au travail proposé. Cela comprend:

- dégagements des gaz et ventilation
- venues d'eau souterraine
- exposition au bitume
- contrôle de terrain dans le calcaire et dans les sables pétrolifères
- forage et sautage
- analyse des dangers
- procédés opérationnels
- formation et direction

14. RECHERCHE ADDITIONNELLE

Cette étude décrit aussi brièvement un travail de recherche additionnelle qui pourrait être fait à partir du tunnel creusé dans les sables bitumeux, y compris:

- une perméabilité assistée obtenue de diverses manières telles que la fracturation provenant d'explosifs, d'un jet d'eau ou d'un effondrement
- des essais avec injection de vapeur
- une excavation par voie hydraulique

15. OUVERTURES

Ce rapport se veut une évaluation adéquate des problèmes de développement des sables pétrolifères. Les expériences proposées peuvent aussi représenter de bonnes ouvertures pour l'industrie minière.

16. CONCLUSIONS

A titre de conclusion, les simples expériences proposées ici fourniraient des renseignements détaillés importants à partir desquels les méthodes in situ de récupération assistée pourraient être adéquatement évaluées.

SECTION 1

INTRODUCTION

SECTION 1

INTRODUCTION

Supply and Services Canada, on behalf of Energy, Mines and Resources, have identified a need for specific research addressing the application of underground mining techniques to increasing exploitation of the vast reserves of the Alberta oil sands.

There are three basic concepts for the recovery of bitumen from oil sands which utilize underground mining. The first concept involves construction of shafts and tunnels by means of which men and equipment can be placed close to, or even within, the reservoir to apply in situ methods. The second concept involves deliberately fracturing and disturbing the oil sands by the underground extraction of a very limited fraction of the material in order to improve the permeability of the reservoir for in situ processes. In the third concept oil sand is mined by underground operations and transported to the surface for processing.

The Underground Test Facility is being developed by the Alberta Oil Sands Technology and Research Authority primarily to carry out field tests on the first concept. However the facility may, under certain circumstances, provide an opportunity for either of the other two concepts to be investigated.

Although numerous studies have addressed the use of underground mining methods to either extract oil sand or to provide underground access for in situ process techniques, they have all been conceptual, and have been limited by a lack of data on in situ oil sand behaviour. There is no underground field experience of any significance which can be used to evaluate the potential of these concepts.

This report describes a series of underground experiments which will provide the initial basic data on in situ oil sand behaviour that is required to properly evaluate the potential for applications of underground mining techniques in oil sands. The experiments will provide data on caving, fracture generation, material strengths and oil sand failure around openings, spalling, gas emissions, oil sand handling underground, equipment related concerns and numerous other aspects.

Implementation of the experiments requires the identification of a suitable site at the Underground Test Facility and also the permission of AOSTRA and possible operating partners. All experimental activities would be required to meet the standards of the operating practices of the UTF management and to meet two basic conditions:

- They should not interfere with the primary purpose of the facility which is to test in situ methods applied from tunnels,

- They should not place at risk the integrity of the facility or the safety of personnel.

The experiments that are proposed are modest and relatively simple because the present information base is too narrow to design comprehensive, detailed experiments that are technically credible. The primary objectives of these experiments is to expand the existing information base so that future underground oil sands mining can be addressed with a sound technical understanding of the unique characteristics of the oil sands.

The authors are of the view that a staged program is required to progressively add to the data base and thereby quantify the implied risks of underground oil sands mining.

The experiments are described in a conceptual way only; detailed design can only be undertaken when a specific site has been identified at the UTF. In spite of their simplicity they represent activities at the frontier of oil sand research. They will provide basic and essential information which is fundamental to all future applications of underground mining activities in oil sand.

SECTION 2

BACKGROUND

SECTION 2

BACKGROUND

2.1 THE OIL SANDS IN ALBERTA

The most striking feature of the Canadian oil sands deposits is their sheer size. The reserves of bitumen in the Athabasca oil sands of Alberta are estimated to be 1 trillion Bbl in place. Crude bitumen forms more than 90% of the total liquid hydrocarbon resource in Canada and must therefore be a prime target for development to render the country energy self sufficient and possibly a net exporter of oil.

The difficulty of recovering bitumen from reserves too deep for surface mining is perhaps the most difficult aspect of economically exploiting the resource.

Two operations now producing synthetic crude from the Athabasca oil sands depend on surface mining of shallow deposits of less than 75 meters and the extraction of bitumen from the mined sand. Unfortunately only approximately 5% of the total reserve of oil sand in place is suitable for recovery by surface mining at this time. Between the depths of 75 and 200 meters the oil sand deposits are considered too deep for oil sands mining and not deep enough for in situ methods due to the shallow cover, making high pressure steam injection impractical. This reserve has so far proven to be extremely difficult to recover economically and at an acceptable recovery of the oil in place. The efforts to exploit reserves deeper than 200 meters have utilized a wide variety of in situ recovery processes applied through wells drilled from the surface. As of December, 1983, forty-four in situ pilot schemes of various sizes had been constructed in Alberta. The most common methods are based on thermal stimulation which involve using heat to reduce the viscosity of bitumen. Many of these methods produce bitumen and are technically feasible, but it remains to be proven whether they can operate economically and continuously at commercial scale while recovering an acceptable percentage of the oil in place.

In the Athabasca oil sands the major difficulties encountered by in situ operations applied from surface wells include:

- serious problems in obtaining communication between adjacent wells due to the extremely low permeability of oil sand. If communication is not established heat cannot be efficiently transferred and oil will not flow readily to the producing well.
- great difficulty in encouraging uniform heating of the reservoirs due to the presence of clays and silts or water bearing sands between layers of bitumen rich sands.
- loss of heat in the portion of the wells above the reservoir or through permeable beds above the oil sand.

It is quite possible that, for the Athabasca oil sands, much of the difficulty experienced in operating in situ processes successfully may be alleviated by creating permeability within the reservoir using various underground mining techniques to disturb the beds prior to in situ operations.

2.2 THE UNDERGROUND TEST FACILITY

During the past several years AOSTRA has received several proposals for the recovery of bitumen using underground mining techniques. Some proposed that underground tunnels be developed, either in the oil sand reservoir or in the adjacent strata, to allow men and equipment to be placed in or close to the pay zone for the application of in situ techniques. Other concepts involved the mining of oil sands using hydraulic jets or mechanized longwall mining techniques.

During 1976 and 1977, AOSTRA, together with five oil companies (Haston, 1978) commissioned a study to evaluate the potential of Mine Assisted In

Situ Processing (MAISP). The purpose of the study was to examine the feasibility of applying thermal in situ processes using horizontal wells drilled from a network of tunnels in close proximity to the oil sand. This study was followed by an outcrop test of horizontal drilling and steam injection techniques conducted by Petro Canada Ltd. in 1979.

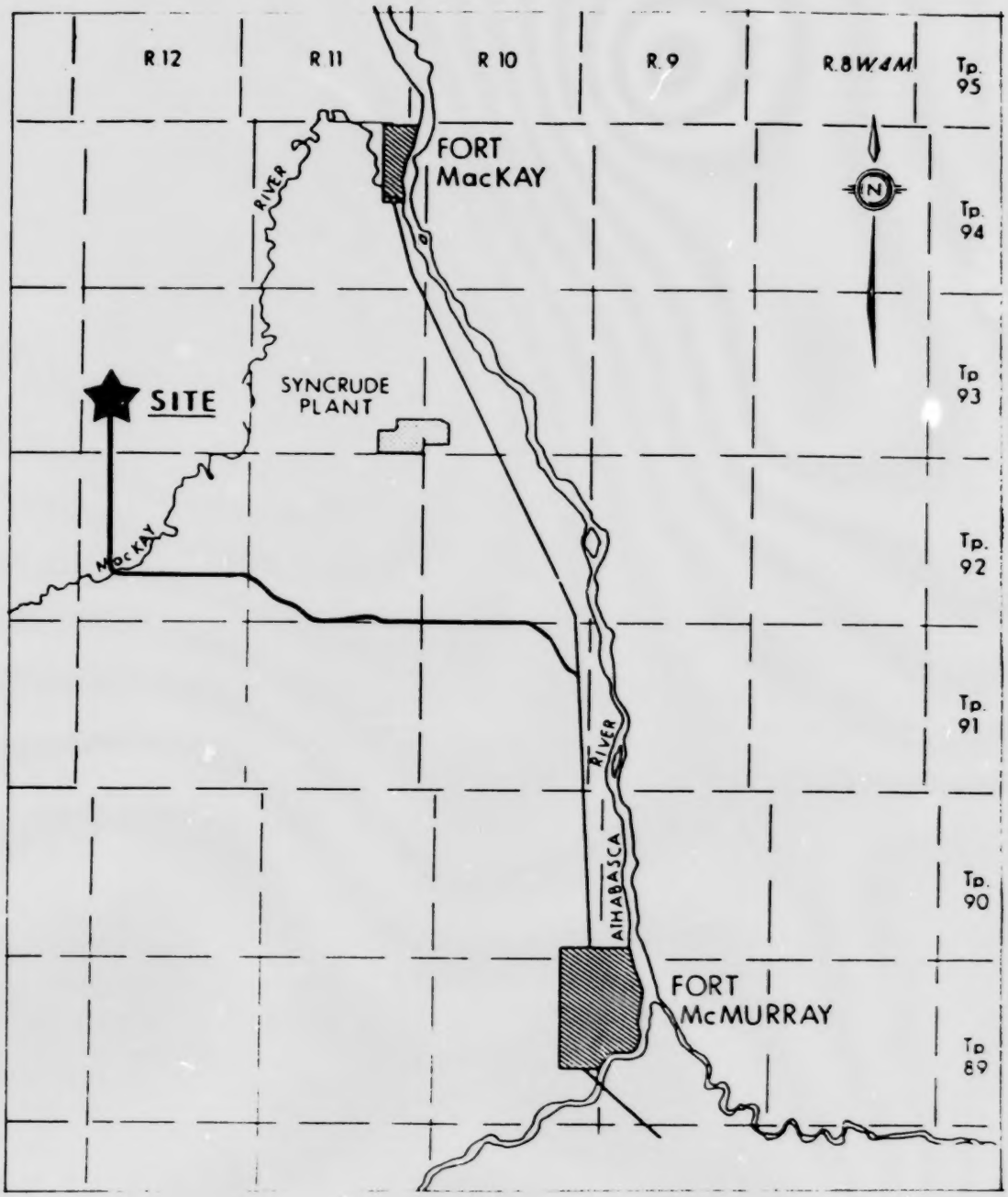
Other studies were initiated by Esso Resources Canada Ltd., and by AOSTRA, together with Gulf Canada Resources, Inc. While the results of all studies indicated that under the right conditions substantial benefits could arise from the application of mine assisted in situ process techniques, all were limited by the lack of data, and were based on purely conceptual mining studies.

In December, 1982, AOSTRA retained Norwest Resource Consultants Ltd. to undertake a site specific design of an Underground Test Facility (UTF) at a site approximately 17 km west of the Syncrude operation. (Figure 2-1) The facility would provide a valuable research opportunity and could be used to evaluate alternative in situ recovery processes applied through horizontal wells drilled from tunnels. Initially, the facility will consist of two shafts, 223 meters deep, approximately 1000 meters of tunnels, and associated surface facilities.

At the time of writing, construction of the facility is in progress and two shafts have been successfully completed.

Shaft design parameters are:

Ventilation capability	35 cubic m/sec.
Material handling capacity	100 tonnes/hour
Conveyance dimension	2.34 m x 1.6 m
Shaft depth	223 m to shaft bottom



DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY LOCATION MAP
DATE JUNE, 1985
SOURCE E.R.C.B. Application
FIGURE 2 - 1

Tunnels will be driven away from both shafts, and will be 4 m x 5 m in cross section. Underground development will include an equipment assembly station, electrical switch room, refuge chamber, and a loading pocket station.

The facility is described in considerable detail in Stephenson, et al (1985). When construction is completed, the UTF will have in place all the necessary services and facilities, both above and below ground, to allow implementation of the experiments proposed in this report to take place. Implementation of the experiments will therefore require minimal construction or capital cost to gain what might otherwise be extremely expensive information.

2.3 NEED FOR THE STUDY

The Athabasca oil sands represent a unique challenge for the underground mining community, by providing an environment with a very difficult combination of problems. Those problems, some of which may be unique to the oil sands, are described below.

- It is known that when the strata pressure of the oil sand is released (for example by excavation) the gases dissolved in bitumen and water rapidly come out of solution and the fabric of the oil sand is destroyed. As the gas is released the material expands until a new condition of stability is reached. This phenomenon is most commonly observed when cores are taken from the oil sand during exploration drilling. Preliminary research shows that chilling or freezing the oil sand does not significantly diminish the rate of gas exsolution or the effect of exsolution on the oil sand structure. Because of this phenomena the in-situ properties of oil sand have never been directly and satisfactorily measured.
- Because of the abrasive nature of oil sand conventional underground mining and transportation equipment could be subjected to a degree of wear that could well be intolerable. Equipment life could be very short and the cost of maintenance very high.

- Transportation and handling of oil sand will be difficult in an underground environment. Experience at the surface mines of Suncor and Syncrude shows that oil sand is very difficult to handle. Transfer chutes have to be very steep, have replaceable decks and sometimes need to be heated to prevent sticking. Conveyor belts are difficult to keep clean and conveyor rollers have a short life.
- No established precedent exists for underground excavations, at any great depth, in the Athabasca oil sands.
- Due to the difficulty in carrying out in situ testing of gas emission rates, the types of gas given off and consequently the ventilation requirements for excavation in oil sands are unknown.
- The difficulties caused by the leaching of bitumen from the reservoir (by drainage water for example) may be a serious problem with liquid bitumen creating traction problems for men and equipment as well as great difficulty in keeping the operation clean, and a possible health hazard.

2.4 MINING ENHANCED IN SITU SCHEMES

Partial excavation of a deeply buried oil sand reserve would result in caving, fracturing, etc. of the deposit. It is envisaged that the recovery, by thermal in situ means, of bitumen from the oil sands could be enhanced by controlled use of this partial extraction process. In general, the following advantages might be achieved.

1. Gravity drainage could be promoted because of the fracturing of horizontal barriers of low permeability such as clays and siltstones. Such barriers are a serious impediment to normal in situ operations.
2. Drainage rates could be increased because of the much higher general permeability of the expanded reservoir. The permeability of undisturbed oil sand is extremely low.
3. If improved drainage rates occur, less time would be required for production and heat losses to the overburden would be reduced. This

should result in a better oil/steam ratio, the most significant factor in the economics of in situ operations.

4. Low pressure steam could be employed thus reducing the consumption of energy.

Again, only by observation and measurement in an underground experimental situation can the needed data be obtained. Only when the necessary basic data on oil sand behaviour adjacent to underground excavations is available can an adequate assessment of the advantages of thermal in situ process schemes be made.

In summary, the mining expertise and data which would be obtained from the experiments proposed in this report are fundamental for the Canadian underground mining and petroleum industries if underground mining of oil sands or mining enhanced in situ process schemes are ever to be adequately assessed.

SECTION 3

DATA REVIEW

SECTION 3

DATA REVIEW

3.1 LITERATURE REVIEW

A thorough and comprehensive literature review was conducted prior to the design stage in order to ensure that all relevant information pertaining to mining systems and in-situ operations of oil sands was considered. The objectives were to compile a list of all data sources and their relevant technical papers. Those papers which were found to be of particular use to the project were obtained and are listed in the annotated bibliography.

Initially the literature review involved compiling a preliminary list of references which were deliberately selected to represent a broad spectrum of disciplines. Sources investigated included several bibliographies and computer data base files. Computer data base files searched included the following:

Data Base	Source
AOSI	University of Alberta and Alberta Research Council Oil Sands Data Base, Alberta Oil Sands Information Centre.
Compendex	Abstracted Information from World's Significant Engineering and Technological Literature. The computer form of the engineering index.
DOE	One of the world's largest sources of literature references on all aspects of energy and related topics. Maintained by the United States Department of Energy.

Georef	Produced by American Geological Institute. 40% of indexed publications from the U.S.
Mintel	CANMET's data base.
NTIS	National Technical information service data base consists of United States government - sponsored research, development and engineering plus analyses prepared by Federal Agencies, their contractors or grantees.
EBIB	Energy bibliography and index which covers production and utilization of fossil fuels.
EDB	Energy data base - comprehensive coverage on literature patents, monograms, and technical reports covering all aspects of energy production and utilization, prepared by the U.S. Dept. of Energy.
Occupational Safety & Health	A product of the clearing house for Canadian occupational health and safety.
Claims/U.S. Patent Abstracts	Patents listed in the general, chemical, electrical and mechanical sections of the U.S. patent office.

Data sources which were reviewed but failed to produce any applicable references include:

Coal	International Energy Agency
Engineering Meetings	Index to significant published proceedings of engineering and technical conferences. (cross referenced with compendex)
Geoarchives	A comprehensive geoscience database.
Electrical Power DB	References to research and development projects of interest to the electric power industry including fossil fuels. Records include abstracts of project summaries for past and ongoing research projects.
Energy Line	Computer form of energy information abstract information on scientific, technical and planning aspects of energy.

In addition, attempts to enter into the Tulsa University data source were made but not successfully completed due to censorship. Access to these data bases is restricted to authorized non-profit organizations or individuals.

Tulsa	Petroleum abstracts offered by the University of Tulsa.

The key words used to compile this preliminary reference list were consistently used for all data sources and consisted of the following:

> Oil Sands or Oil Shales; Mining, Underground, Tunnels, In-situ, Extraction, Blasting, Freezing, Caving, Fracturing, Permeability, Instrumentation, Monitoring, Drilling.

During the course of the review additional references and information were gathered from academic and industrial contacts. Drs. D.F. Scott and E.M. Gates of the University of Alberta were contacted along with Mr. Real

Doucet of Suncor and Mr. T. Lord of Syncrude. Valuable data was also obtained from Cominco's patent literature.

References were categorized and screened for their relevance to the study by a project panel and a short list prepared. Hard copies of the selected reference were then obtained from the Alberta Oil Sands Information Centre in Edmonton, and the files of Norwest, Cominco, Thurber, and the University of Alberta. They were then distributed to the designated study participants for reference.

3.2 CURRENT RELATED RESEARCH

Numerous current research programs in many parts of the world will ultimately have a bearing on mining assisted oil extraction techniques. These programs are being supported by both industrial and governmental bodies and have been initiated in large partly due to the basic lack of understanding of in-situ properties of oil sands. Some of these projects are briefly described in Section 3.3.

Canadian research projects range in scale from field pilot programs to laboratory modelling experiments with the majority of these being applied to enhancing the recovery of oil from Alberta's oil sands deposits. The Alberta Oil Sands Technology and Research Authority is funding, in whole or in part, much of the research interest in programs that could utilize the information gained from conducting experiments proposed in this study. A partial list extracted from AOSTRA's 1984 yearly review of some of the more relevant research projects and the key researchers follows.

Dr. J.D. Scott is beginning the 2 years renewal of his professorship at the University of Alberta and will continue the use of analytical modeling techniques and laboratory and field experimental studies to increase basic knowledge of the geotechnical properties of oil sands.

Dr. P.M. Byrne of the University of British Columbia has worked on a method for predicting stress-strain relationships and related stabilities of oil sands, with particular emphasis on conditions appropriate to various excavations. In addition to $30,000 awarded previously, another $28,588 has been made available for continuing support to this project for 16 months.

Dr. J.E. Gillott of the University of Calgary is investigating the changes in strength, dimensions, permeability, and bond characteristics of oil well cements after hydrothermal treatment in the presence of formation fluids and drilling muds. This is a two-year project costing $69,689.

Dr. E.M. Gates and Dr. R. Toogood of the University of Alberta are investigating the cutting of oil sands by high pressure water jets. Total funding for this research and earlier related research begun by Dr. R. Gilpin is $78,157 over four years.

Dr. T.R. Hsu of the University of Manitoba is developing an industrial application oriented computer program to describe the in situ fracturing behavior of oil sand formations subject to optimum combinations of controlled impulse and/or hydraulic loadings. This one-year project will cost $44,760.

Dr. J.B. Hyne of the University of Calgary has been studying the reactions of bitumen, emphasizing sulphur-containing compounds, at temperatures and pressures comparable to in situ recovery conditions. Petro-Canada Exploration Inc. and INTEVEP of Venezuela have purchased access to this program by paying 25% and 50%, respectively, of the cost and are participating in technical planning. AOSTRA's contributions to this project have amounted to $1,106,621 over a seven-year period.

Dr. B.C.Y. Lu of the University of Ottawa is examining the internal consistency of the existing data on gas solubilities in bitumen which are available to AOSTRA. He is also investigating the applicability of various

equations of state which could lead to a simpler method for simulating reservoir performance. This one-year project will cost $25,200.

Dr. N.R. Morgenstern and Dr. J.D. Scott of the University of Alberta have designed and set up a high temperature, high pressure facility and are using the facility to measure strengths, deformabilities, and permeabilities of oil sands at temperatures and pressures encountered in in situ production. This work has been funded to a total of $433,787 over a five-year period.

Dr. E. Nyland of the University of Alberta is developing and testing a field-oriented microseismic monitoring array for monitoring the progress of oil sand and heavy oil in situ recovery processes. This project will cost $282,300 over a two year period. A further $96,564 was made available to Dr. Nyland and Dr. M.B. Dusseault of the University of Waterloo to refine a prototype observing system for microseismic events related to enhanced recovery projects.

Dr. E.W. Neumann of the University of Toronto has developed a new method for investigating surface thermodynamic properties, such as surface tension of bitumen obtained from different extractions of oil sands of different origins and grades. Funding of this research is $240,479 over four years.

Dr. T.J.T. Spanos of the University of Alberta is conducting mathematical analyses of fluid-flow behavior in relation to in situ production. This research will cost $128,410 over a three and one-half year period.

Dr. W.Y. Svrcek and Dr. A.K. Malhotra of the University of Calgary have been measuring the solubilities of gases in bitumen and the viscosities of the resulting gas-bitumen solutions. Total funding has been $490,660 over a period of six years.

Dr. N.C. Wardlaw of the University of Calgary is investigating rock-pore properties in carbonate and sandstone reservoirs in relation to enhanced oil recovery. This project is funded with $146,000 over a two-year period.

Early in 1980, and supplemented early in 1984, AOSTRA agreed to provide a total of $2,115,000 to Alberta Research Council to conduct regional geological studies in oil sand, carbonate and heavy oil areas. The contract provides for work continuing over a four-year period.

In the 1981-82 fiscal year, AOSTRA made provision for the expenditure of $300,000 by the Petroleum Recovery Institute in Calgary for engineering studies of enhanced oil recovery (EOR) possibilities in Alberta. EOR processes are sensitive to reservoir conditions and to rock and fluid parameters. The research program was directed towards identifying suitable locations for tests of particular EOR processes.

AOSTRA provided $64,420 to D.B. Robinson and Associates Ltd. of Edmonton to collect and compile, into a data book, the published and a substantial amount of unpublished information on the thermodynamic and transport properties of bitumens and heavy oils. Specifically these properties include the following: density, vicosity, gas solubility, phase equilibrium ratios, molecular weight, surface and interfacial tension, diffusivity, heat capacity, thermal conductivity and heat of combustion. AOSTRA has recently published this book.

In addition to the above, AOSTRA funded work projects by the United States Department of Energy and other governments and energy companies around the world have research work underway. Much of the foreign research is site specific, as discussed in the following section of this report.

3.3 OIL MINES

Oil mining is not a new concept. It was a feature of numerous local economies prior to the industrial revolution and enjoyed a limited amount of success until the discovery of current conventional production techniques. Until recently, with the advent of higher oil prices, relatively few oil mining ventures have been undertaken with the exception of a few experimental schemes and the major surface mines in the Athabasca Oil Sands.

The best known historical operations are probably those conducted at Pechelbronn, France, and Wietze, W. Germany in the first half of this century. Descriptions of these mines are available in a report by Stone and Webster Engineering Corp. entitled "An Evaluation of Heavy Oil Mining, March, 1983.". Experimental and commercial oil mining projects other than the AOSTRA UTF Project currently in operation or under consideration include:

Devran Petroleums Ltd., Sarnia, Ontario
Conoco Inc., Casper, Wyoming
New Tech Oil Inc., Malta, Ohio
Cornell Heavy Oil Process Inc., Bakersfield, California
Department of Energy, Casper, Wyoming
Petrol Industries Inc., Texas
Northwest Gold Inc., Texas
Yarega and Balakhany Projects, U.S.S.R.
Argentina
Romania

Each of these projects utilizes an underground access scheme to provide increased recovery of either light or heavy oil from reservoirs which were not suitable for conventional production techniques or considered exhausted due to previous production.

3.3.1 Devran Petroleums Ltd., Sarnia, Ontario

In December 1983, Devran Petroleums Ltd. began an extensive coring program in the old Watford - Kerwood and abandoned Sarnia oil pools. The objective of the program was to evaluate the suitability of one of these pools for mine assisted gravity drainage. Devran is currently in the process of sinking a 3 m diameter access shaft into the oil bearing zones to a total depth of 120 m. Two 10 m diameter drilling chambers will be excavated in each of the pay zones and horizontal holes will be drilled. A radial pattern of 24 holes, 740 m in length, is expected to drain an area of approximately 161 ha. Devran anticipates production to begin in early 1986 with volumes of 16 and 80 m^3 of oil/day produced. Initially oil will be produced by gravity drainage however, tests are underway to investigate various EOR techniques.

3.3.2 Conoco Inc. Casper, Wyoming

This is a gravity drainage experimental project in the North Tisdale oil field, 70 miles north of Casper, Wyoming. The reservoir, with an estimated 733 barrels per acre foot, consists of oil-saturated Lakota Sandstone at an average depth of 300 ft. under Tisdale Mountain. The reservoir is an oil ring surrounding a large low pressure gas cap. Due to the absence of natural formational pressure to aid production, development of this reservoir using conventional techniques was not successful.

In 1977, Conoco first drilled a 70 m well to confirm the presence of enough oil-saturated sandstone to warrant a mining scheme and to verify reservoir depth and attitude for mine access design. A 300 m long horizontal adit was driven, supported by timber and steel beams until it entered the competent Lakota Sandstone. Within the Lakota Sandstone split set roof bolts were used for support. Later, a ventilation shaft was excavated.

Conoco drilled horizontal wells from the tunnel with hydraulically patented operated machinery that its research division developed for coal seam

degasification. A specially designed diamond bit was used to drill the hard sandstone. Control of well deviation was critical because drilling has to remain as close as possible to the bottom of the sandstone. Six horizontal holes were drilled for gravity drainage, ranging in length from 75 to 520 meters. The oil drained into the main production sump at the wellhead and was pumped to the surface where oil and water are separated. During the first year production averaged 68 barrels per day and has since stabilized at 29 barrels per day.

The second stage of the project involved sinking a large diameter shaft to the producing formation where seven horizontal drainholes of 8.25 cm diameter, ranging from 120 to 440 meters long, were drilled from an underground chamber at the base of the shaft.

The project appears to be technically successful but not profitable. The operation has been turned over to New Tech Oil Inc. of Spokane, Washington. During discussions Conaco staff indicated that minimum H_2S and CH_4 gas problems were encountered. Drills experimented with included Watson, Atlas Copco and others. Extensive instrumentation for monitoring of strata conditions and drill deviation is being used, which they feel will be the key to success.

3.3.3 New Tech Oil Inc., Malta, Ohio

Another gravity drainage project exists at the 1500-acre Buck Run field near Malta, Ohio. The reservoir was first tapped in 1861 and has been producing oil using conventional extraction methods at an ever decreasing rate since then.

New Tech Oil Inc. initially began to experiment with various extraction techniques prior to developing a commercial gravity drainage operation. Different holes patterns, angles and spacings were attempted from various horizons, along with experimenting with enhanced recovery methods; steam

and water reinjection together with various polymers, hydraulic fracturing and repressurization have all been used. It appears however that ultimately the most cost effective and efficient method of extraction was to tunnel below the reservoir and drill vertically, or angled upwards into the reservoir, and allow the oil to drain by gravity. Thin, impermeable shale layers distributed throughout the formation prevented the oil from percolating downward into horizontally drilled holes.

The present operation consists of a 45 m shaft with two 162 m drifts running horizontally under the reservoir. Miners fan drilled 117 holes, each about 60 m long at various angles up through the formation. Each hole is cased in plastic and steel, and the oil drains at a rate of approximately one quarter barrel per day per hole.

The extraction should be in the order of 50 to 80 percent of the remaining oil, which is estimated as 10,000 barrels per acre.

3.3.4 Cornell Heavy Oil Process Inc., (Hopco) Bakersfield, California

For over a year, Hopco has run a pilot project in the Kern River Field near Bakersfield, California, which was considered a marginal field after conventional thermal recovery experienced poor results. At a 25 acre demonstration site, Hopco sunk an 2.13 m diameter shaft to 150 meters. From a drill chamber constructed at the base of the shaft, eight horizontal wells in a hub and spoke pattern were drilled using a proprietary augering technique; four to 215 m and four to 130 m. Each well carries a slotted casing, which distributes steam during stimulation and produces oil. For maximum thermal efficiency eight conventional vertical steam injection wells which intersect the underground horizontal well pattern were also drilled.

The company expects to recover 75 percent of the oil in place, and targets about 700 to 900 barrels per day production from the pilot facility. They hope to expand the project to the remaining 255 acres, to yield 4000 to

6000 barrels per day by the end of the decade if financial backing by D.O.E. Synfuels Group is obtained.

Hopco is currently assessing heavy oil prospects in other parts of the United States and abroad to apply its process.

3.3.5 Department of Energy, Casper, Wyoming

During 1984 the United States Department of Energy conducted a study on the installation of a subsurface oil drainage system for the Shannon Reservoir at the Naval Petroleum Reserve, located 64 km north of Casper, Wyoming. The reservoir consists of lenticular sandstones of Cretaceous age. The shallow, low pressure, oil bearing sandstone reservoir is 38 m thick and consists of two separate pay zones with each considered for gravity drainage. Depth of operations is expected to be 200 meters and the underground work environment is expected to be gassy. This project is still in the feasibility stage and future development is contingent on D.O.E. funding.

3.3.6 Petrol Industries Inc., Texas

It was announced during 1982 that Petrol Industries, Inc., Shreveport, Louisiana was planning to start a light oil mining project in the Caddo-Pine Island field. A feasibility study determined that the project could produce in excess of 2 million bbl of 41^{o} - 43^{o} gravity oil in the first 2 years of full operation.

Core analyses showed that zones existed with average porosity of 25.3%, horizontal permiability of 0.2 md and an average residual ore saturation of 22.8 of pore space.

The project calls for a vertical shaft to be sunk just below a shale layer under the upper Cretacous Annona chalk. Horizontal tunnels would be excavated around the shaft and wells would be drilled from these horizontal

tunnels upward about 45 m into the Annona formation. Oil would drain by gravity and be pumped out. First efforts might encompass about 40 acres.

Besides the initial 40 acre project site, Petrol's leased acreage in the area contains 17 other 40 acre sites. Petrol also plans to drill 80 development wells in Caddo-Pine Island Field to the Shallower Upper Cretaceous Nacatoch. No information on the current status of this project is available at this time.

3.3.7 Northwest Gold Inc., Texas

Northwest Gold Co. of Wyoming is currently in the process of developing an oil mining project in the Taylor Ina Field, Medina County near Hondo, Texas. The reservoir contains 20% of the initial oil reserves.

The oil producing zone is located 60 m below ground and consists of several 7.6 m thick layers which contain 34 - 35^{o} API oil. The producing zone has been reached with a 60 m deep, 1.5 m diameter (1.2 m ID) shaft. A 7.6 m long, 3.0 m high, and 3.2 m wide drilling chamber has been excavated for spoke drilling of drainage holes. Approximately 50-100 drainage holes will be drilled (horizontal, updip, downdip) in order to intersect as much of the oil zone as possible. These holes will be 8.25 cm in diameter and extend up to 300 m in length. Drained oil will be collected in a main sump tank and be pumped to the surface with a submersible pump.

Further information on production and cost is not available at this time. The project will cover approximately 160 acres of the field.

3.3.8 Yarega and Balakhany Projects, U.S.S.R.

In recovering highly viscous oil, Soviet specialists use a combined method of oil mining and thermal stimulation. The thermal method developed in the 1970's has successfully increased recovery at three 40 year old mines.

The reservoir at Yarega is 70 m thick and lies at a depth of about 180 m. A recovery of only 2 percent is achieved by conventionally drilled wells with surface pumps. In the Yarega project, horizontal and inclined holes each 180 to 240 m long have been drilled from an underground mine. Some of these are used to inject steam into the formation and others to produce oil. The spacing of the holes is about 15 m or less. Using this system, the Soviets have achieved oil recovery of 50-60% with about four years required to drain the reservoir in the mine area. The oil has a viscosity of 15,000-20,000 cp at reservoir temperature of 43°F.

The reservoir consists of a competent consolidated sandstone and tunnels can be constructed without the need for supporting the walls or roof. With such a system, part of the production is achieved by seepage through the tunnel wall and this together with the production from the wells is collected in sumps at atmospheric pressure and pumped to the surface. While there is an advantage to unsupported walls, there is also a disadvantage in that the introduction of steam into the reservoir must be conducted carefully in order to prevent breakthrough into the tunnel. This limits the steam pressure which can be employed and in turn limits the temperature and the viscosity reduction of the moving oil.

The oil, heated by the steam fed from the surface, flows into a lower horizontal zone, then is separated from the water and pumped out. The Yarega mines have already produced some 60 million bbl of high quality oil. Plans exist to increase oil production at Yarega considerably in the 1980's.

An oil mine is also under construction in the Balakhany field in Azerbaijan. In this mine, oil flows along slightly inclined boreholes into a corridor under the productive strata and is then pumped to the surface through the mine shaft. The recovery factor here is 80 to 90%. The oil produced is of high quality, heavy grade.

3.3.9 Yacimentos Petroliferos Fiscales, Southern Argentina

The state oil company of Argentina, Yacimentos Petroliferos Fiscales (YPF) is planning to conduct a chemically-aided oil mine project. Initial injection is scheduled to begin in 1987 in a pilot area at a depth of 350 metres. The commercial project will be at a depth of 750-850 metres.

The process, called the UROG process houses all the production facilities in a 3.5 metre-diameter vertical shaft. The shaft is drilled to 30 meters below the bottom of the producing formation. Once the shaft is drilled, directional injection wells are drilled above the area to be produced.

Oil is collected near the bottom of the producing formation where most of the sediments are removed before the oil is pumped to the surface.

The project will be remote controlled with a full alarm and monitoring system intact to alert the operator of any malfunctions.

3.3.10 Romania

Crude oil production by mining in Romania has been active since 1925. The past success of this activity has resulted in the country's priority program of Enhanced Oil Recovery. The main target for mining activities are those reserves which occur less than 300 to 500 meters below the ground surface. Intense investigations of these deposits are centered on research programs and field experiments which have the objective of improving the old mining technologies and also developing new techniques.

The Sarata-Monteoru mine is currently in operation and has produced over 300,000 tonnes of crude oil with a recovery factor in the 55-60% range. Initially, the gravity drainage of crude oil was used through galleries and later, horizontal and descending wells. Based on the results obtained so far, 188,000 bbl. per year will be produced by 1987 and the technology is planned to be extended to other reserves.

Two other pilot mines exist. These are Runco Bustenari and Sdont. The current status of these projects were not available at the time of writing.

SECTION 4

GEOLOGY, GEOTECHNICAL AND HYDROGEOLOGY

SECTION 4

GEOLOGY, GEOTECHNICAL AND HYDROGEOLOGY

4.1 GEOLOGY

The total bitumen in place in the area proximate to the UTF site is estimated at 52.0 x 10^6 tonnes or 51.7 x 10^6 m^3 (325.3 x 10^6 barrels). Approximately 35 percent (about 115 million barrels) is present on Crown Land and 65 percent on Petro Canada Exploration Inc. Oil Sands Lease No. 09 82 030002. The main ore body of the McMurray formation has an approximately planar lower surface which lies unconformably on Devonian Limestone and an irregular upper surface. Grades within the main ore body are high and increase toward the base of the McMurray formation. Occassional zones of low permeability or barrier horizons exist with only minor basal clays and water-bearing sands found. A thin potential gas-bearing zone may be present at the contact between the Clearwater and McMurray formations. Gas did not cause problems during exploratory drilling and pressures are expected to be low.

The overburden consists of sediments from the upper McMurray, Clearwater and Grand Rapids formations, together with glacial materials. Overburden thickness near the UTF ranges from 120 metres to 150 metres.

For a detailed review of geological conditions at the UTF site refer to Appendix A-1.

4.2 GEOTECHNICAL

Geotechnical investigations commenced at the test site in early 1983. The studies included terrain analysis, review of existing geologic and hydrogeologic information, drilling of geotechnical test holes, piezometer installations,

laboratory testing and analysis. Aspects of hydrogeology are discussed in Section 4.3.

The shafts have penetrated approximately 165 m of silts, clays, claystones, sands and oil sands of the Grand Rapids, Clearwater and McMurray formations. These strata are mostly poorly indurated and only sporadically cemented. Sandstone and siltstone beds are present locally. At a depth of about 165 m the shafts encountered, and penetrated, Devonian limestone.

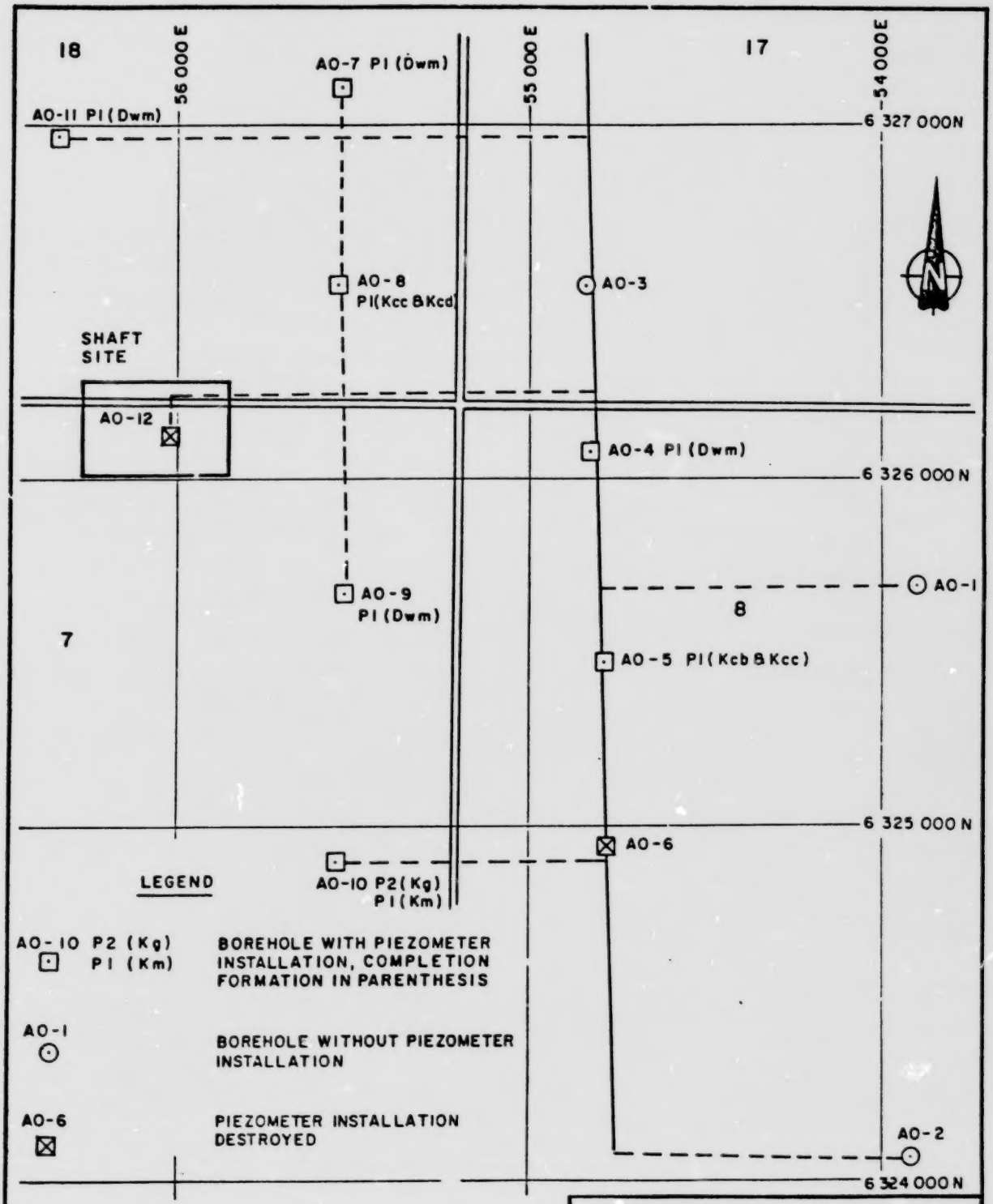
For a detailed review of the results of the geotechnical investigations refer to Appendix A-2.

4.3 HYDROGEOLOGY

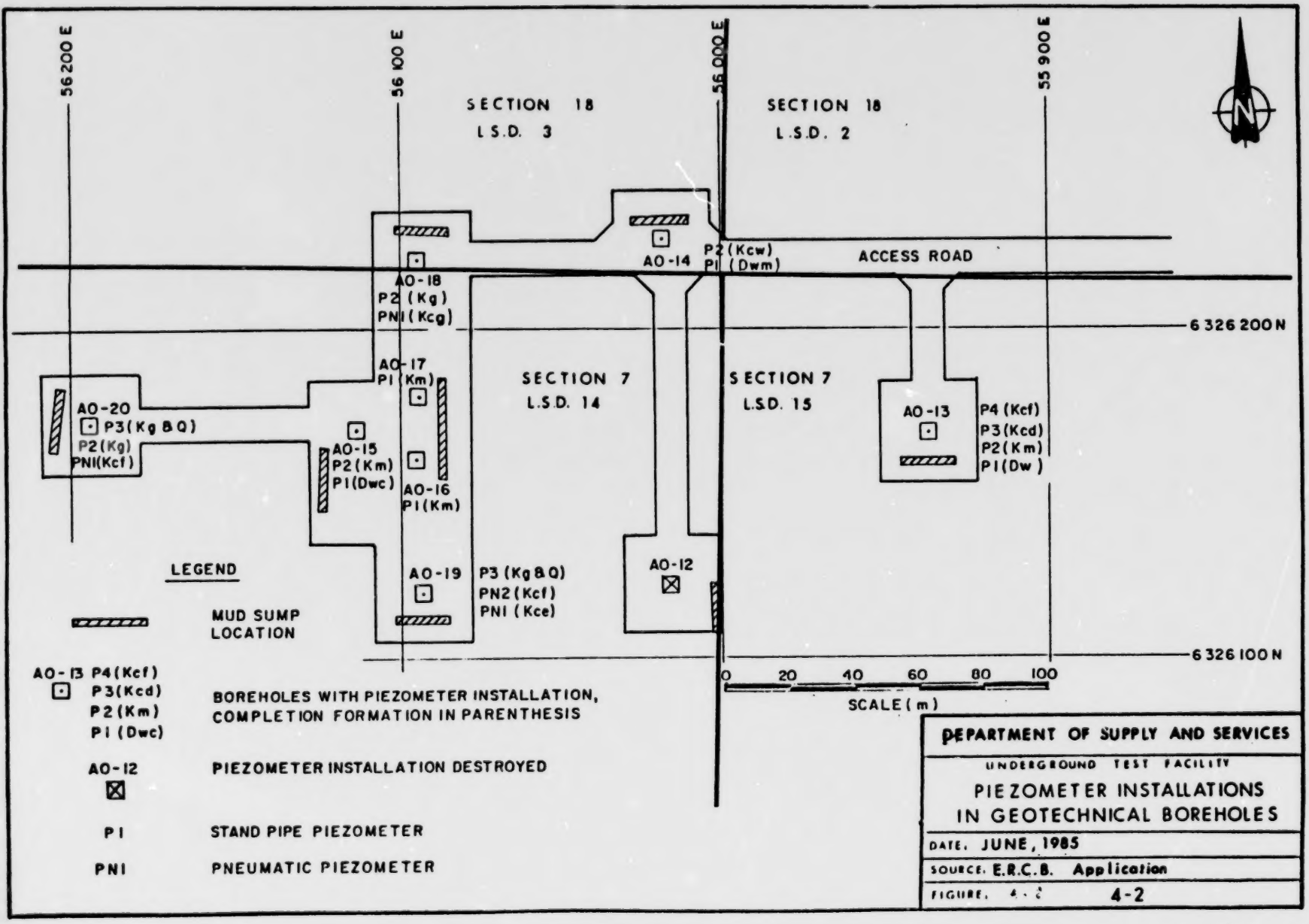
During the field exploration program, 8 standpipe piezometers were installed in the geological holes (Figure 4-1) and a total of 18 piezometers (14 standpipes and 4 pneumatics) in the geotechnical holes (Figure 4-2).

Due to the necessity to demobilize the equipment and reclaim the area before spring break-up, complete development of standpipe piezometer installations was not always satisfactorily accomplished. Thus the interpretation of rising or falling head tests may not reflect the true hydraulic conductivity of the formation in certain piezometers. Results indicate that hydraulic conductivities are low and that no high yield aquifers are present. There is no McMurray basal aquifer at the shaft site nor is there evidence of karst or collapse features in the Devonian at the shaft site.

Site specific groundwater quality chemical analyses are limited in number due to incomplete development of piezometer installations. Site specific analytical data has been complemented by information obtained from the Alberta Research Council's observation wells in the area. Available evidence indicates all groundwater will be brackish to saline.



DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY PIEZOMETER INSTALLATIONS IN GEOLOGICAL DRILL HOLES
DATE: JUNE 1985
SOURCE: E.R.C.B. Application
FIGURE: 4-1



DEPARTMENT OF SUPPLY AND SERVICES

UNDERGROUND TEST FACILITY

PIEZOMETER INSTALLATIONS IN GEOTECHNICAL BOREHOLES

DATE. JUNE, 1985

SOURCE. E.R.C.B. Application

FIGURE. 4-2

Appendix A-3 outlines the results of the hydrological investigations conducted at the UTF site.

SECTION 5

APPLICATION OF UNDERGROUND MINING TECHNOLOGY

SECTION 5

APPLICATION OF UNDERGROUND MINING TECHNOLOGY

5.1 INTRODUCTION

Although at present open pit mining produces the major portion of the oil from these deposits, the reserve base amenable to this method of extraction is limited. The in situ recovery of bitumen from the oil sand deposits offers the greatest potential for maximizing the utilization of this vast resource.

The advantages of conventional in situ recovery techniques compared to current surface mining techniques can be listed as follows:

(a) Problems associated with handling large quantities of excavated oil sands are eliminated.

(b) There is no need for tailings disposal, thus eliminating the adverse environmental impacts of tailings ponds.

(c) Part of the oil extraction process is accomplished underground thereby reducing the capital costs of surface installations and eliminating the associated operating costs.

(d) Surface disturbance from open pit mining is eliminated and subsidence following bitumen extraction is minimal.

A variety of in situ recovery techniques, using wells drilled from the surface, are currently being used or investigated by the oil industry. With many of these techniques fracturing is employed to enhance the permeability of the oil bearing formation, thereby improving the recovery of bitumen. However, the overall resource recovery is low with the present in situ technology and there is ample room for improvement. Furthermore, all of the in situ

techniques are located in deep deposits, over 250 m in depth. Shallow deposits, which are still too deep for surface mining, are not considered to be suitable for the in situ technology presently available.

Underground mining techniques, integrated with present in situ oil technology, may improve resource recovery and may open up the portion of the oil sands reserve which, until now, has not been seriously considered as extractable - namely the deposits that are too deep for surface mining and too shallow for conventional in situ recovery.

Three concepts for utilizing underground mining technology can be considered in exploiting oil sands:

(1) provide access closer to the oil sands than obtained from surface drilled wells. (SATAC)

(2) increase the permeability of the reservoir through partial extraction of the oil sands and by blasting.

(3) bulk mine the oil sands.

These three areas of application are discussed in the remainder of this section.

In the consultants opinion only options 1 and 2 are worthy of serious considerations in the foreseeable future.

5.2 UNDERGROUND ACCESS

This concept is presently being tested by AOSTRA. To date, it has been demonstrated that a shaft can be sunk through all the formations, including the oil sands, into the Devonian Limestone which forms the base of the deposit. It is expected that underground development can be driven within the basal limestone without any difficulty and that wells can be drilled from this relatively close location into the oil sands reservoir. These wells would

serve the same function as surface wells for conventional in situ extraction methods. A detailed description of this concept was presented by Stephenson, 1985.

5.3 MINING ENHANCED IN SITU SYSTEM

The key to improving in situ recovery of bitumen from oil sands is to increase the permeability of the reservoir so that the injected steam or other agent can be more efficiently used. The main possibilities that are considered for increasing the permeability are:

- Blasting to produce fractures within the oil sands zone.
- Induced subsidence.
- Partial extraction using underground mining methods.

5.3.1 Blasting Methods

The use of explosives to dynamically generate fractures in intermediate and deep oil sand reservoirs has not been considered to be as successful as blasting in the surface operations. Current research in this field includes work by J.D. Scott (1985) of the University of Alberta and J.F. Cuderman (1984) of Sandia National Laboratories, Albequerque, N.M. The work by Scott is directly applicable to oil sands whereas the Sandia Laboratories objectives were to stimulate production in oil shale.

Both projects utilize propellants of the progressively burning type instead of conventional explosives. Tailored pulse loading of the explosive charge helps to control the compressive "stress cage" which inhibits the permeability enhancement by plugging the newly formed fractures and locally increasing the breakdown pressure of the formation. Multiple orientation of fractures is reportedly possible in situations where hydraulic fracturing is likely to result in only one or possibly two principal directions.

The series of experiments conducted by Sandia Laboratories was carried out in tunnels where horizontal drillholes were loaded with propellants and ignited to produce multiple fractures. The drillholes and disturbed zone were subsequently mined back for fracture observation.

The conclusions of these studies and others indicate that the application of blasting techniques to aid in situ recovery of oil sands is technically feasible.

5.3.2 Subsidence By Extraction of Underlying Formation

Another mining concept which has potential for enhancing the permeability of the oil sand formation is the creation of voids within the underlying formations. By extracting the limestone or the underlying Prairie Evaporite, either conventionally or by solution methods, subsidence and relaxation of the overlying McMurray formation might be induced. In situ techniques could then be applied to the fractured zone.

Problems which could arise include:

1. Problems with the stability and safety of openings adjacent to the subsidence area.
2. Disposal of waste salt, although it could be dissolved and injected into deeper aquifers, a technique which is utilized in the potash industry.
3. Increased ground stress in abutment areas until full subsidence has taken place.
4. The height of the void must be controlled in order to limit the maximum total subsidence. If fractures and increased permeability are created in zones above the oil bearing formations the control of in situ processes will be difficult and energy will be wasted. If solution methods are used much of the technology is patented.

Although this is an interesting approach, the ability to maintain control is questionable and makes this one of the least viable alternatives.

5.3.3 Partial Extraction

Partial extraction involves removal of a portion of the oil sands to create voids, thus inducing the collapse of the formation to form a more loosely compacted and a more permeable zone that will show improved response to in situ extraction techniques.

Conventional underground mining methods that can be used to partially extract a portion of the oil sands should focus on undercutting the oil sands zone to encourage the collapse of the upper portion of the deposit. The techniques most suitable for this function are:

- longwall mining
- room and pillar mining
- hydraulic mining
- block caving

Any partial extraction method will require an underground materials handling system and surface extraction facilities to process the excavated oil sand and dispose of the tailings.

Except for hydraulic mining, all of the proposed techniques are sensitive to the presence of the "basal aquifer". If this is present, dewatering is required before the techniques can be used.

Longwall Mining

The extraction of a single slice, 2.5 to 3 metres in height, at the base of the deposit using longwall methods may be a technically feasible approach to partial extraction. Mining activity is concentrated within the oil sands and therefore will have to address the unique characteristics of the material.

The following aspects relating to equipment and procedures would have to be considered.

(1) The problems of utilizing self advancing hydraulically operated shields in oil sands. In particular, the nature and behaviour of the oil sand forming the roof and the material forming the floor, which may be Devonian limestone or part of the McMurray formation.

(2) The behaviour of an unsupported face in oil sand as the longwall operation moves forward and the expected tendency of this face to collapse and slough possibly to such an extent that the strata cannot be controlled.

(3) The effect of abutment pressures ahead of and behind the face.

(4) The abrasive effect of oil sand on the cutting, loading and conveying equipment or on sensitive parts of the hydraulic suppports and in particular the fire hazard which may arise when oil sand is cut or impacted by high speed equipment.

(5) The tendency of oil sand to accumulate on the equipment.

(6) The ventilation requirements for the concentrated extraction of oil sands inherent in longwall operations.

Room and Pillar Mining

Room and pillar mining would be conducted within the base of the oil sands deposit. This approach has been proposed by Harris (1978) and Stone and Webster (1984). By nature, this technique provides an increased level of stability to the overlying oil sand compared to the longwall method; nevertheless, voids represented by the dimensions of the rooms will be created in the undercut and a certain amount of collapse can be expected. A better

understanding of the characteristics of in situ oil sands is required to determine a room and pillar configuration which would provide the required effect on the upper part of the oil sand formation and at the same time offer a safe working environment. Other specific operating problems that are unique to the oil sands and which will require particular attention when using room and pillar systems are as follows:

(1) Trafficability of floor to accommodate mobile equipment.
(2) Ventilation requirements in a labour intensive environment to overcome gas emissions from the deposit and equipment, if diesel powered.
(3) The problems of abrasion and stickiness of oil sands mentioned in the section on longwall mining.

Hydraulic Mining

A number of hydraulic methods have been proposed in the literature with the majority assuming the Waterways formation would be used as access (K. Mathews, 1980 and M.C. Harris, 1978). However, research is currently being conducted by Syncrude into the hydraulic mining of oil sands from boreholes drilled from the surface (C.W. Wagner, 1984) and the results may be applicable to this project. Also of relevance is the research being conducted by Dr. E.M. Gates of the University of Alberta who has been intensely involved in the study of water jet piercing of oil sands. His work could be applied in either a mining or fracturing situation.

A possible advantage of utilizing hydraulic methods to extract or create voids in the oil sands is that the introduction of ground water from the saturated overburden would not be as great a concern as with conventional mining methods and may in fact aid the creation of an oil sand slurry over much larger areas than the limited range of the water jet.

The use of slurry pipelines would minimize the problem of gases in the underground environment and provide a cleaner method of handling the sticky material.

Block Caving

With this method, all the development is located in the underlying limestone. Access and haulage drifts are initially driven at a spacing determined by the draw characteristics of the mining block. Coned drawpoints are then driven to the base of the mining block and enlarged as the oil sands contact is approached with the objective of establishing a continuous undercut. The spacing of the drawpoints is also a function of the flow characteristics of the oil sand. Clearly this parameter has to be quantified to allow the haulage drifts and drawpoints to be properly located.

It is expected that the angle of draw in oil sands will be steep, requiring extensive development to promote natural caving. Fan drilling and blasting may be incorporated with this method to more effectively open the undercut and at the same time reduce the amount of development. Hydraulic methods combined with pipeline transport may also be used for this function to reduce the amount of development.

The block caving technique provides a certain amount of flexibility in establishing the proper height of the undercut. Since the work is performed from within the relatively safe limestone horizon, the height of the undercut that can be taken is a function of the limits imposed by drilling or hydraulic jetting rather than safety considerations. Undoubtedly a higher undercut can be taken with this approach compared to techniques such as longwall and room and pillar, both of which place men and equipment within the undercut in oil sands.

Only enough material would be drawn from the undercut to develop caving; the area then has to be prepared for steam injection and will likely require

total sealing. The wells for steam injection will have to be drilled from a separate heading which is isolated from any of the workings used for mining.

The block caving technique offers good potential for application and warrants further investigation of design parameters to allow more credible mine planning.

5.4 BULK EXTRACTION

It is highly unlikely that bulk extraction of oil sand, using conventional underground methods, would be economically viable or operationally practical.

The present oil price cannot economically justify a bulk underground mining scenario in the near future. Underground equipment productivity does not approach the rates attained by surface mining equipment presently in use. An underground operation would be a labour and equipment intensive mine with high operating and capital costs. Since the oil sand would be subject to the same surface treatment as presently used by surface mines similar costs can be expected for extraction, upgrading, tailings disposal, site infrastructure and reclamation. These costs may in fact be somewhat higher because underground bulk mining cannot attain the same degree of selectivity as surface operations and because dispersal of tailings and reclamation may be even more complex.

Depending on the grade of the deposit, anywhere from 1.5 to 2.0 tonnes of sand has to be mined for 1 barrel of oil. To develop a mine capable of producing 50,000 barrels of oil per day, the underground mine would have to produce a minimum of 75,000 tonnes or possibly 100,00 tonnes daily. This is an order of magnitude larger than any underground mining operation the consultants are aware of. Considering the difficult handling characteristics

of the oil sand it is not certain that underground transportation systems can be developed to handle this volume.

It is much more reasonable to consider underground mining in a support role - to provide close access to the oil sands and to increase permeability of the formation through partial extraction.

5.5 USE OF UNDERGROUND MINING TECHNIQUES

For this reason the consultants believe that, if conventional underground mining or tunneling techniques have a future application for recovering bitumen from oil sands, it is almost certain to be as a means of placing in situ systems close to the reservoir, i.e. the Shaft and Tunnel Access concept, or for improving the permeability of the reservoir by partial extraction, i.e. the Mining Enhanced In Situ System. It is quite possible that a combination of these two concepts may be particularly effective on suitable reservoirs.

Unconventional underground mining techniques, such as remote hydraulic mining systems using jet cutting and slurry transportation, may on the other hand have potential for producing oil sand for surface processing.

SECTION 6

PROPOSED EXPERIMENTAL PROGRAM

SECTION 6

PROPOSED EXPERIMENTAL PROGRAM

6.1 INTRODUCTION

As reviewed previously in Section 5, there are a significant number of different concepts available to enhance the recovery of oil sands resources by utilizing underground mining techniques. While some of the concepts are believed to have significantly better commercial potential than others, there is, for all cases, a lack of adequate information on in situ oil sand behavior to reliably assess either their technical or economic feasibilities.

The AOSTRA Underground Test Facility has determined the cost of shaft access to the Waterways Limestone formation and will soon be confirming the cost of tunneling at a safe horizon in the limestone itself. Once this stage is complete, the cost of access below the oil sands will be defined. The remaining and major challenge will be to determine the most viable method a facility such as the U.T.F. can utilize for the recovery of the bitumen resource. While it is acknowledged that enhanced recovery techniques currently being investigated by the oil industry hold much promise, it must also be recognized that the application of mining techniques may further enhance the oil recovery, or provide an extraction alternative.

A review of public domain literature indicates the following key geotechnical areas where additional information is required to assist in evaluating the alternate mine assisted recovery methods:

- **Gas Exsolution:** It is generally accepted that the gas exsolution process will substantially affect the stability of the oil sands adjacent to any free face such as a tunnel wall. While some experience was gained in excavating the Saline Creek tunnel, the gas pressures measured were relatively low presumably due to the near surface

location and outcrop extent and geometry. It is believed the gases substantially bled off over time, prior to tunnel construction. The Saline Creek tunnel did not therefore provide any information which would allow reliable predictions of the behavior of a tunnel face in deep oil sands to be made. The effects of gas release on tunnel stability at depth cannot be confidently predicted at this time.

- **Potential Volume of Gas In-flows:** The Saline Creek tunnel and the G.C.O.S. test shaft are the only significant underground openings excavated in oil sands to date. Gas volumes encountered in those two excavations were low enough not to present ventilation difficulties. Samples taken from drill holes at depth also indicate relatively low volumes of gas from rich oil sands, although obtaining true values is admittedly difficult. Zones consisting of barren sand exist and are expected to contain significant volumes of gas. Full scale tests are required to confirm these predictions and to determine the range of potential in-flows that can be expected.

- **In Situ Strength of Oil Sand:** Laboratory analysis of core samples of oil sands taken from depth have been conducted. Methods to remove the samples with as little sample disruption as possible and methods to simulate "in situ" conditions during testing have improved in recent years. There still remains concern as to how accurate the results of these simulated "undisturbed" samples are. Secondly, the age old concern remains of how well laboratory results can be extrapolated to accurately predict full scale bulk properties. The practical effects of the material strength will not be definitively determined until full scale excavation at depth demonstrates the bulk behavior of the oil sands.

- **Porosity and Permeability Enhancement:** Depending on depth, conventional oil technology for enhancing oil sand porosity and permeability is limited. If porosity and permeability can be improved,

the potential of in situ bitumen recovery is significantly increased. Mining assisted permeability enhancement through partial oil sand extraction processes and/or extending permeability with explosives have been considered but not tested in practice.

- **Practical Problems of Equipment Design:** Oil sand is a sticky, abrasive material. Experience gained with the Saline Creek tunnel and surface mine operations have demonstrated the adverse effect of these properties on mining costs. Any underground method involving the physical extraction of oil sand will have to develop or adapt equipment to cope with this. While there is reason to expect that these problems can be overcome, it will be an expensive, lengthy process of development.

This report proposes a series of three discrete experiments that will provide initial answers and insight into a number of the questions raised above. The proposed experiments are believed to be practical and can be conducted in a logical, conservative sequence. Once the experimental work has begun it is likely that initial information obtained will affect the design of the remaining proposed work program.

6.2 PHASE I - PRE OIL SAND ACCESS PHASE

6.2.1 Objectives

The introduction to the proposed experimental program discussed key areas where technical information is lacking. This information is required to assist in the evaluation of alternate mine assisted recovery methods. Phase I of the proposed experimental program consists of two experiments. Both of these experiments are designed to obtain basic geotechnical information on the behavior of oil sands when exposed to openings at depth.

The first experiment (Phase IA) is a caving experiment and consists of gradually expanding an opening below the McMurray formation to measure the caving behavior of oil sands. The excavation and monitoring of this experiment would be conducted from the safety of the Waterways formation. Section 6.4 entitled "Observations", details the key geotechnical parameters intended to be observed and measured. This cautious first step of making an opening into the oil sands will confirm the practicality of the proposed Phase II experiment. The proposed Phase II experiment consists of excavating a short test tunnel located in oil sand at the base of the McMurray formation.

The second Phase I proposal (Phase IB) is a permeability enhancement experiment. After completing the caving experiment, the area of influence of the caving will be determined by the monitoring program. It is proposed to attempt to extend this area of enhanced permeability by displacing undisturbed material towards the caved area by blasting. Monitoring before and after the blast will indicate how the permeability over a larger area has been affected. All of the requirements and facilities for the permeability enhancement tests will exist at the end of the caving experiment except for the actual drilling and loading of the explosives. The costs for conducting the blasting experiment will be minimal.

6.2.2 Location and Site Characteristics

As discussed in Section 2.2, the UTF facility developed by AOSTRA is the preferred location to perform the series of experiments. The UTF provides the necessary safe access to the Waterways formation below the oil sands as well as the necessary services and facilities that will be required during the project.

Initial drilling in the area of the UTF indicated that conditions would be favourable for the series of experiments considered. Specific physical advantages of the site conditions are:

Water Potential: Drilling in the area did not intersect any major aquifers in the McMurray formation. This does not rule out the potential for relatively low pressure water at the contact between the McMurray and Clearwater formations. Intersection of pockets of barren sand (up to 2 m thick) within the McMurray formation or at the McMurray/Waterways contact may contain limited quantities of water. Any water intersected is expected to be below theoretical hydrostatic head.

Gas Potential: There is potential for a thin gas-bearing zone at the McMurray/Waterways formation contact, and in any barren zones within the McMurray formation. Drilling in the area did not encounter problems due to gas, and any gas encountered is expected to be of low pressure and limited volume.

Uniformity of Oil Sands: In the UTF area the McMurray formation is 35 to 40 meters thick with the lower 20-25 meters considered exploitable. The estuarine member contains from 11.8 to 15.6% oil by weight based on 12 holes drilled in the area in 1983. The McMurray formation generally follows the trend of the underlying Waterways formation.

Structural Dip: The top of the Waterways limestone is gently dipping to the west at a gradient of approximately 5 meters per kilometer. The limestone bedding is relatively flat with dips rarely exceeding 2^{o}.

Depth: In situ testing of oil sand behavior at depth is the primary objective of the experiments. Since the base of the oil sand is approximately 170 meters deep in the vicinity of the shaft, the U.T.F. satisfies this criteria.

Secure Tunnel Horizon: It is proposed that for the experiment the top of the access tunnel lies immediately below the 1.2 meter thick massive limestone bed, about 8 meters below the sand - limestone contact.

Undisturbed Test Site: The only experience to date in tunneling in oil sands was the Saline Creek project. While it provided a wealth of information, its primary limitation was that due to the exposed area of the oil sand, much of the original gas pressures had bled off. The gas exsolution process is believed to have a very significant effect on oil sand stability around excavations. The extrapolation of Saline Creek experience to other in situ sites is considered limited. The AOSTRA UTF site would be the first opportunity for detailed observation of oil sand behavior in an undisturbed environment at depth. Information from this site should be reliable for application to other locations within the Athabasca region.

Minimizing Experiment Cost: With access already available into the Waterways formation, infrastructure on site and drill hole data already available, the cost of conducting an underground experiment is greatly reduced compared to other comparable sites.

6.2.3 Staging and Access

Staging

Assuming authorization is obtained to conduct the experimental projects from the AOSTRA Underground Test Facility, staging will be simplified. The UTF is being designed for the specific purpose of hosting experimental projects. The series of experiments proposed in this report require the following:

Surface Facilities: Offices, change house, shops etc., are provided in the UTF plans, although consideration of other projects that may be proceeding concurrently may limit the use of these facilities.

Excavated Material Hoisting: Facilities will be in place for hoisting excavated limestone delivered to the shaft by L.H.D. The proposed experiments may be the first to require hoisting of excavated oil sand material at this new facility. The prospect of having to overcome initial debugging of the

materials handling system when loading and unloading oil sand in the shaft conveyance and tunnel transportation system must be considered. The planned 100 tph hoisting capacity will be adequate for any of the experiments proposed in this report. Disposal requirements for material hoisted to surface has not been finalized to date.

Ventilation: Preliminary UTF design plans include a main fan capable of providing adequate ventilation for 6 cubic meters per second of fresh air to up to 3 tunnel faces concurrently. It is assumed the project proposed will be required to supply its own auxilliary fans and ducting for local ventilation.

AOSTRA will be establishing codes for acceptable ventilation standards. All equipment must meet applicable requirements for use in gaseous mines.

Electrical Services: The proposed project will likely be required to provide the power system from the shaft bottom to the test area. At this time, details of main power supplies available at the shaft bottom have not been determined.

Mobile Equipment: It is assumed the project will be required to supply its own mobile equipment for personnel transport, materials handling and excavated materials disposal. All equipment must meet applicable standards for use in a gassy environment.

Drilling Equipment: It is assumed the project will be required to supply its own drilling rig. This is expected to be electrically powered, hydraulically driven, and able to accommodate required blow-out prevention systems. This drill must be approved for use in a gassy environment.

Communications: Communications from the work areas to the surface will be essential. The UTF will have a phone system, which the project would extend into its assigned test area at its own cost.

First Aid and Mine Rescue Facilities: It will be necessary to determine what, if any, of the first aid, mine rescue facilities and personnel need to be supplied by the project.

Pumping Facilities: Prior to opening the test facilities for use, provisions for pumping water out of the mine will be in place. It is assumed that piping and local pump requirements in the proposed test area will be required to be supplied by the project. The pumping capacity would be designed to handle minor water inflows only less than 75 litres/min.

Access

Site Access: The UTF has an all-weather road that will allow all necessary equipment and materials to be trucked to the site.

Shafts: The site is designed so that normally all personnel, equipment, materials and debris are hoisted in No. 1 Shaft. It will have an unobstructed diameter of 2.7 meters for any large materials handling requirements. Emergency egress facilities for personnel will be available in No. 2 Shaft.

Main Access Tunnels: Main access tunnels initially will be limited to the shaft area. Present plans call for only 350 meters of tunnels to be installed. Depending on the timing of the proposed experiment, additional main access tunnels will be required. Current plans are for main access tunnels to be 4 meters high by 5 meters wide. These dimensions will be large enough to allow passage of any equipment forseen to be required for the proposed experiments. Confirmation of these dimensions should be made during the detailed project planning stage.

Main access entry systems are proposed to consist of two drifts separated by a 30 meter pillar and will be located about 15 m below the base of the McMurray formation (Figure 6-1). This places the tunnel systems almost entirely within a massive limestone unit to ensure tunnel security. A program

AVERAGE THK.(m)	THICKNESS RGE.(m)	UNIT THK.(m)	ROCK TYPE	COLUMN	PROBABLE TUNNEL HORIZONS
				OIL SANDS	
7·1	3·2 – 12·7	7·1	ARGILLACEOUS LIMESTONE		8·3 m / 15·2 m
1·2	0·5 – 1·8	1·2	MASSIVE (BIOGENIC) Ls.		
2·3	1·6 – 3·3	2·3	ARGILLACEOUS (BRECCIATED) Ls.		
4·6	4·2 – 5·0	4·6	MASSIVE (BIOHERMAL) Ls.		29 m
13·4	13·4 – 13·5	0·4	ARG. (BRECCIATED) LIMESTONE		
		1·8	MASSIVE LIMESTONE		
		0·4	ARG. (BRECCIATED) LIMESTONE		
		3·8	MASSIVE (ARG.) LIMESTONE		
		3·0	ARG. (BRECCIATED) LIMESTONE		
		1·7	MASSIVE LIMESTONE		
		0·7	ARG. (BRECCIATED) LIMESTONE		
		1·6	MASSIVE LIMESTONE		
11·9	10·9 – 12·4	9·2	LIMESTONE SHALE		
		2·7	ARGILLACEOUS LIMESTONE		
			CALCAREOUS SHALE		

PROBABLE TUNNEL HORIZONS

FIG. 6-1

of test drilling in advance of all tunnels being driven is required to eliminate the possibility of tunnelling into water courses, gas inflows or major disruptions of the limestone formation.

Ground support is expected to consist of roof bolts, mesh and/or shotcrete.

Test Area Access: Selection of the test area will be based on a number of factors listed below:

1. UTF Security
   The location selected for the proposed experiments must be adequately separated from the shaft area and other proposed test areas. This is to ensure that the strata affected is confined to the test area. Expected subsidence angles should be the criteria to define the required separation.

2. Minimization of Costs
   Obviously the test area should be located as close to the shaft area as possible (taking into consideration item 1 above) to minimize both tunneling costs and haulage distance for limestone and oil sand material excavated.

3. Representative Site
   The Phase I and II experiments are of relatively small scale. It is important that the oil sands in the area of the experiments be as representative as possible of the UTF area as a whole. At present geotechnical data is limited to the shaft site area. Testing will likely be necessary prior to commencing the experiments to confirm the suitability of the test site selected.

4. Tunnel Horizons
   It is assumed the main access tunnels throughout the test facility will be located within the Moberly member for security. The two test site

access tunnels will remain at the same elevation for approximately 20 m (Figure 6-2). At this point the tunnels would be inclined at 8% until a secure tunnel roof is established. This will be immediately below the crystalline massive limestone bed located approximately 8 meters below the top of the Waterways formation. Tunnel dimensions in the test area will be minimized to reduce tunneling costs and improve stability. Final dimensions will be based on equipment selection and experimental procedure requirements. Dimensions will be no larger than the 4 m x 5 m main access tunnels.

6.2.4 Experiment Description - Phase IA

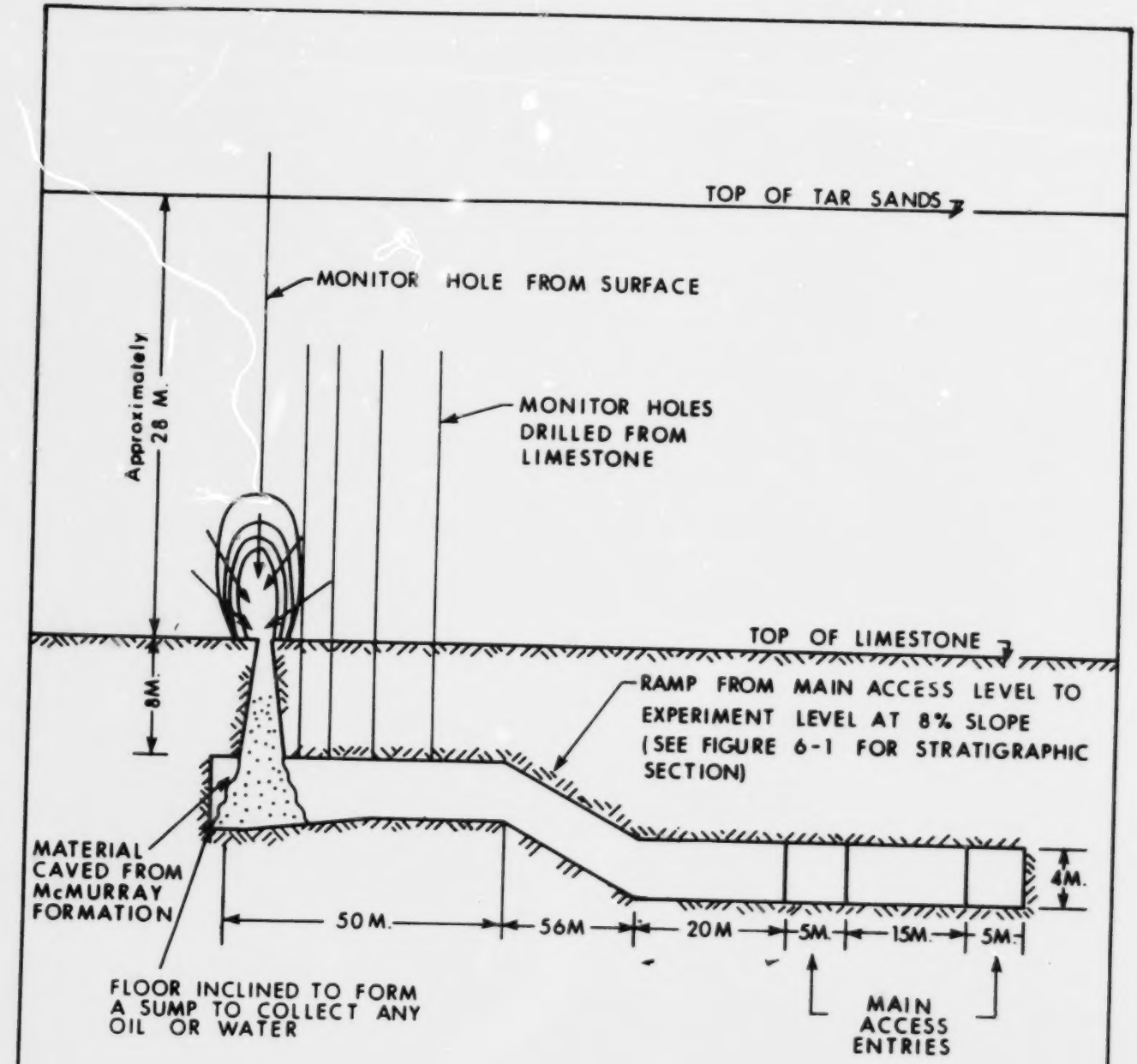
Proposed Layout

The proposed layout of Phase IA is shown in Figure 6-3. Key parameters used in proposing the layout were:

Ventilation and Egress: The layout provides for flow-through ventilation in all entries once construction is complete. This also provides for dual routes of egress in the event of an emergency.

Bulkhead Doors: Safety bulkhead doors are located in both access tunnels in the test area. The doors should be designed to be water tight and be capable of withstanding pressures of 2.2 MPa. Hydrostatic heads at this depth would be less than 1.9 MPa allowing for a safety factor in excess of 15%. The bulkhead doors would be located within the Moberly member to ensure the integrity of the ground around the bulkhead doors.

Ramps: All ramps would be designed at 8% slope for ease of negotiation by equipment working in the area. After entering the test area through the bulkhead doors, both the fresh air and exhaust tunnel would ramp up to about 8 meters below the top of the McMurray/Waterways contact. This



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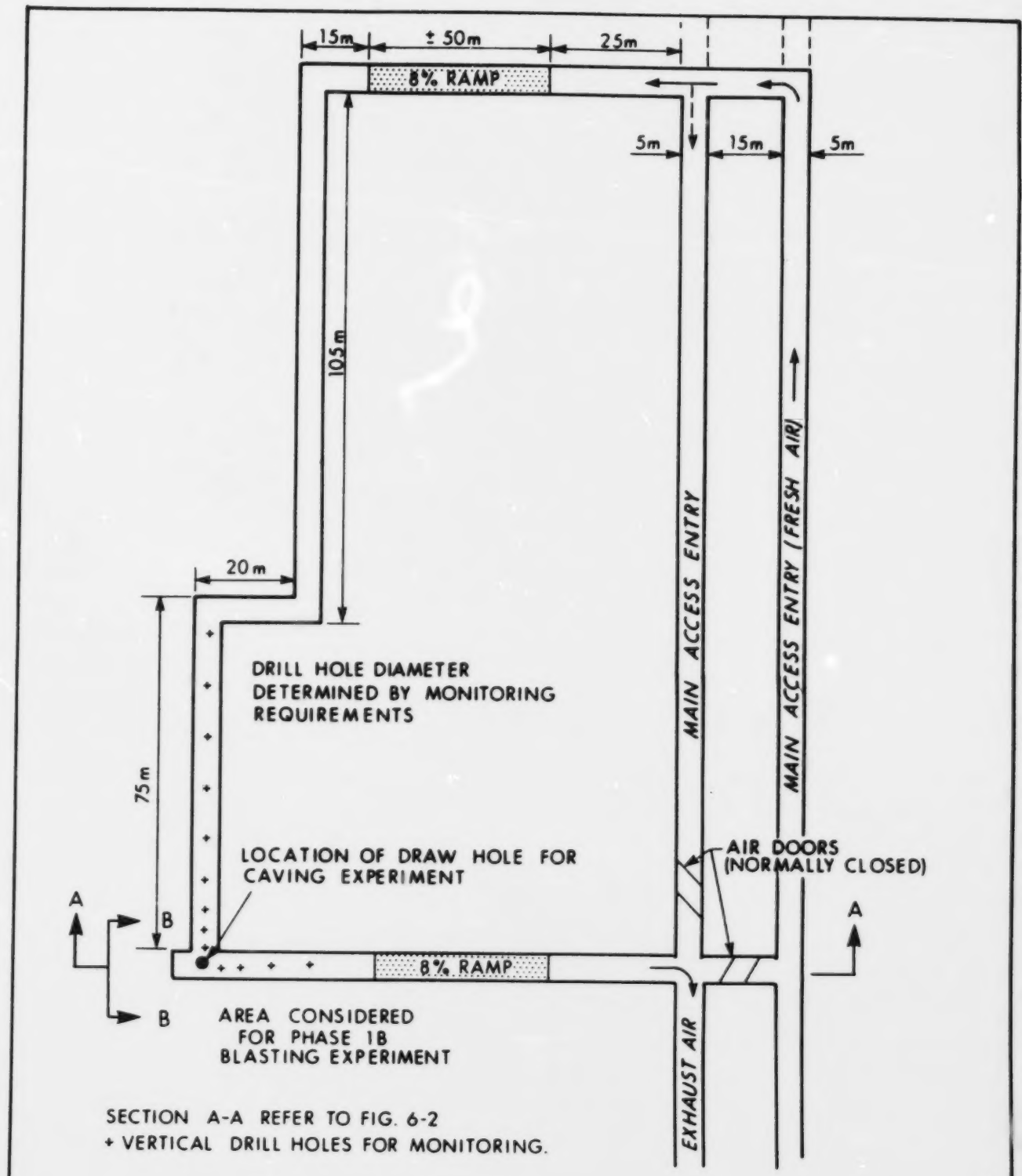
PHASE IA EXPERIMENT
EXCAVATION OF DRAWHOLE
SECTION A-A

FIG. 6-2



DEPARTMENT OF SUPPLY AND SERVICES		
PHASE I A EXPERIMENT DEVELOPMENT PLAN		
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APP.		
		FILE
		FIG. 6-3

provides a 1.2 m thick roof of massive limestone but leaves only 8 m of limestone to drill through for testing and monitoring purposes.

Length of Entries into Test Area: These need to be determined in conjunction with AOSTRA to satisfy any concerns that the oil sand area disturbed will have no influence on other test areas or shaft facilities. It is proposed that the test site be located so that any surface effects still remain within the proposed test area. This would ensure that any effects of the proposed experiments would not interfere with any other work at the site.

Monitoring Sites: All monitoring done from the UTF would be from holes drilled from the access tunnels within the assigned test area to minimize tunneling requirements.

Location of Raise: The test raise should be located at an intersection in the test area. This allows for monitoring in two directions from the affected area and ease of working around the raise.

Test Drilling and Monitoring

1. In Advance of Tunnels
   As previously stated, test drilling is to be advanced ahead of the tunnel system being excavated to locate any hazards from water, gas or disruptions in the limestone beds.

2. From Surface
   Once a proposed area has been selected, a test hole must be drilled from surface to confirm its suitability. The normal expected sequence of stratigraphy and bitumen grades must be present. Furthermore, the absence of major aquifers within the oil sands must be confirmed by the surface hole. The drill hole must also provide accurate location of oil sand/limestone contact elevation for planning purposes and to confirm that no unusual erosion or collapsing of the limestone has

occured in this area. The drill hole will also be used for the installation of accurate (wire type) extensometers to monitor strata movement as the caving experiment proceeds. Precautions to prevent this hole from becoming an access for water from the strata above the McMurray formation and the surface are critical.

A series of subsidence stations should be installed prior to initiating caving. Using standard level surveying techniques any significant surface movement can be accurately monitored to determine the amount of vertical displacement and the area affected.

3. Vertically from Access Tunnels

Prior to starting the caving experiment, test/monitoring holes are to be drilled vertically up from the access tunnels in the limestone. All drillholes holes require blow out preventers anchored into the limestone roof. Hole sizes will be determined by monitoring equipment requirements, but likely will be 50 - 150 mm in diameter.

These holes will detail the elevation of the oil sand/limestone contact, check for any pockets of gas and or water and will house instrumentation for monitoring subsequent testing. As the caving experiment proceeds, results obtained from the monitoring sites will be correlated with time, distance from the drawhole and the amount of material removed from the drawhole. A discussion of monitoring and observations is provided in Section 6.4.

Caving Procedure: In the test area the access tunnels will be about 8 meters below the base of the oil sands. The caving experiment will be done in stages using a draw hole excavated through the base of the oil sands (Figure 6-2). The draw hole will be developed through a combination of drilling and blasting.

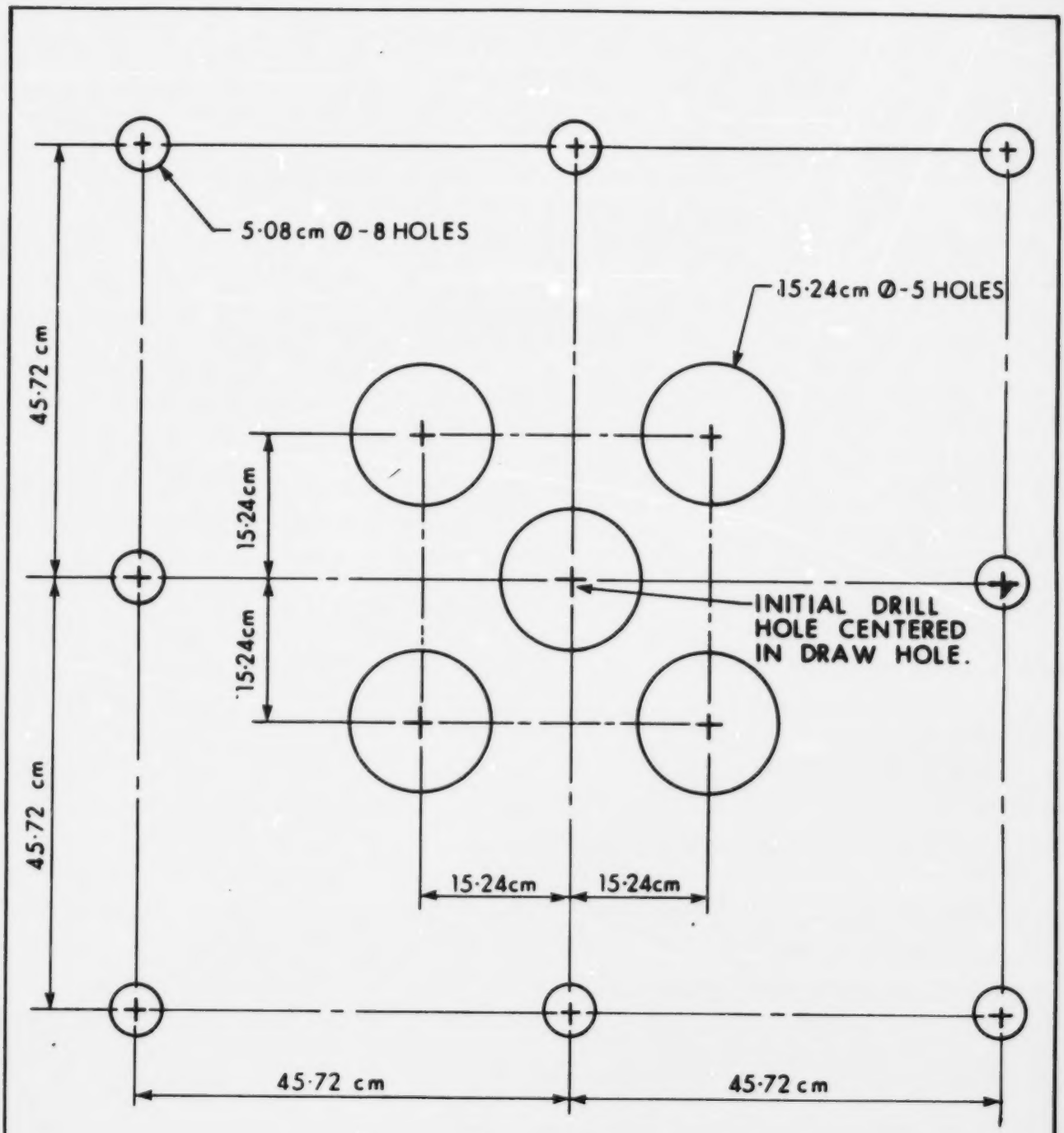
This will involve initially drilling a 100 - 150 mm hole to the oil sand/limestone contact. Once the hole is complete, observation of the tendency for material to flow into the hole and measurement of gas flow rates and composition will be conducted. If any material does flow from the hole the quantities will be obtained and noted with time. After stability has been obtained, the initial blasting pattern will be drilled (Figure 6-4). Only permissible explosives will be used. The blasting pattern suggested is a preliminary design only. The initial blast is critical to obtain an adequate free face for subsequent blasts.

The holes will be pre-drilled for all subsequent blasts so as to eliminate the need to drill from under the edge of the raise as it is widened. The raise is shaped in an inverted cone with sides sloping at least 1 in 12 to prevent material caving into the hole from plugging as it falls the 8 meters into the access tunnel. The opening at the top of the raise first blasted will initially be about 0.9 m x 0.9 m square and incrementally increased in size as follows:

Stage 1 - 150 mm drill hole
Stage 2 - 0.9 m square hole
Stage 3 - 2.0 m diameter
Stage 4 - 3.0 m diameter
Stage 5 - 4.0 m diameter

Consideration may be given to using expanding cement type fracturing agents in preference to explosives after the initial 0.9 m square cut is made. Anticipated difficulties of fragmentation size and loading of the hole would need to be considered prior to making final selection of the rock fragmentation method.

After each stage of widening the raise, the same observations would be made to determine:



DEPARTMENT OF SUPPLY AND SERVICES		
PHASE IA EXPERIMENT DRILL PATTERN TO EXCAVATE DRAWHOLE		
		JUNE 1983
		FIG. 6-4

- amount of material caved.
- changes observed by monitoring stations.
- amounts and rates of gas exsolution.

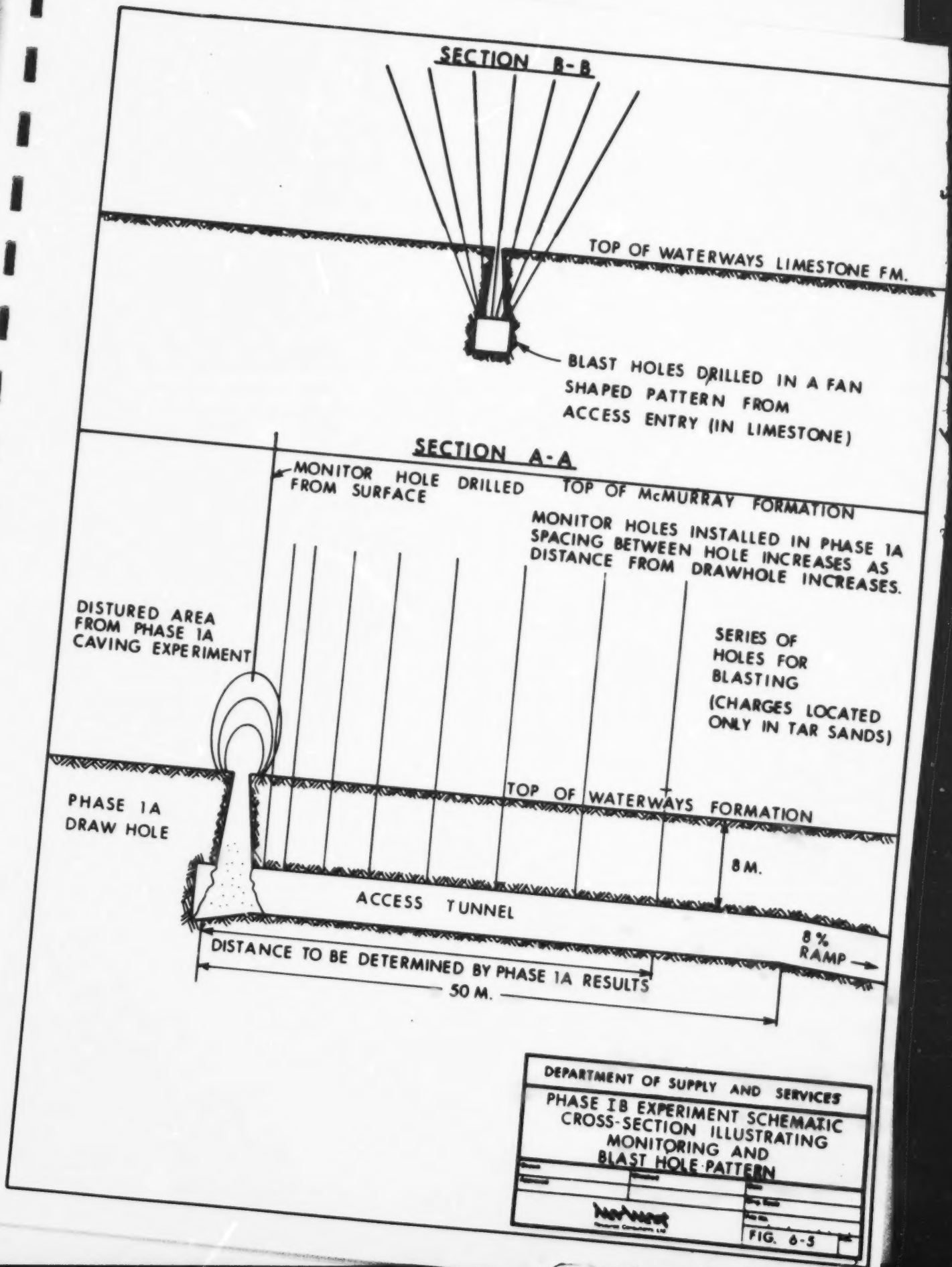
- size and shape of arch formed in the oil sand after the oil sand has stabilized.
- if the hole should be widened further.

Removal of material from the bottom of the raise will be stopped when the first sign of an open raise is observed. This will maintain a plug at the bottom of the raise to protect personnel from any debris falling from the the raise. The time required to conduct each stage of the caving experiment cannot be predicted in advance but would be determined from the observations made during the course of the experiment.

6.2.5 Experiment Description - Phase IB

Once the Phase IA experiment is complete, it is expected that either a stable arch or a high porosity zone will exist around the drawhole. In the Phase IB experiment it is proposed to extend the area of permeability by drilling a fan shaped series of holes, loading the holes with the appropriate low velocity charges and blasting the oil sand toward the drawhole (see Figure 6-5). After the blast is complete, any test holes damaged by the blast should be redrilled to determine the changes in porosity and pore pressures. Any material sloughing from the draw hole should be removed and measured.

Detailed design of the blast layout and the distance of the blast from the drawhole will be determined after completion of the caving experiment. The area affected by the caving experiment, Phase 1A, will have been determined at this time.


SECTION B-B
TOP OF WATERWAYS LIMESTONE FM.
BLAST HOLES DRILLED IN A FAN SHAPED PATTERN FROM ACCESS ENTRY (IN LIMESTONE)
SECTION A-A
MONITOR HOLE DRILLED FROM SURFACE
TOP OF McMURRAY FORMATION
MONITOR HOLES INSTALLED IN PHASE 1A SPACING BETWEEN HOLE INCREASES AS DISTANCE FROM DRAWHOLE INCREASES.
DISTURED AREA FROM PHASE 1A CAVING EXPERIMENT
SERIES OF HOLES FOR BLASTING (CHARGES LOCATED ONLY IN TAR SANDS)
TOP OF WATERWAYS FORMATION
PHASE 1A DRAW HOLE
8 M.
ACCESS TUNNEL
8 % RAMP
DISTANCE TO BE DETERMINED BY PHASE 1A RESULTS
50 M.
DEPARTMENT OF SUPPLY AND SERVICES
PHASE IB EXPERIMENT SCHEMATIC CROSS-SECTION ILLUSTRATING MONITORING AND BLAST HOLE PATTERN
FIG. 6-5

Depending on the results of the initial fan blast, Phase 1B may be extended to include the blasting and monitoring of additional fans.

The cost of conducting Phase IB will be minimal as it utilizes entries in the limestone already developed in Phase IA. It is anticipated that monitoring of the Phase IB experiment would be inexpensive. Required instrumentation would be reinstalled in the limestone drill holes previously used in Phase IA. This would only require redrilling of the portions of the holes located in the oil sands, and reinstallation of the instrumentation.

6.3 PHASE II TUNNELING IN OIL SAND

6.3.1 Objectives

Most of the oil sands recovery processes discussed in the section on Application of Underground Mining Technology (Section 5) require excavation of oil sands to occur as part of the extraction process or as an aid to enhance in situ recovery methods. The Saline Creek tunnel project demonstrated the ability to excavate a tunnel in oil sand in a shallow, low gas pressure environment using conventional mining equipment. At present there is a wide range of opinions as to the relative ease or difficulty expected to occur when tunneling in oil sand at depth.

The AOSTRA Underground Test Facility provides an excellent test site to answer these questions as it provides access to the base of the oil sands at a depth of about 170 meters. At this depth both the in situ stresses and gas pore pressures are substantially higher than experienced in the Saline Creek tunnel. It is proposed to conduct a test excavation of a tunnel in oil sands from the UTF facility. The objectives of a test tunnel would be as follows:

Excavation Methods: The Saline Creek tunnel was excavated using a conventional road header mining machine with no major modifications to

adapt it to the expected conditions. Apart from problems with abrasiveness and stickiness, the cutability of oil sands was not a problem. In a deeper environment, the tunnel face may require restraint to prevent sand being pushed into the tunnel by ground pressure. The expansion of residual pore gas will probably cause swelling of the oil sands. In this particular fragmented state, the oil sands should be amendable to direct mucking by the excavation equipment. Trials are required to observe the extent of this process to define if there may be excavation methods that can be adapted to better cope with or even utilize this slabbing and spalling phenomena.

Tunnel Support System: The expected loads imposed on a tunnel lining system cannot be reliably predicted based on currently available information. The excavation process will de-stress the ground immediately adjacent to the opening and, it is suggested that loads on tunnel supports will not exceed about half the total in situ stress prior to excavation. Tunnel linings must be designed to allow for continued draining of the gas and minor water to prevent build up of hydrostatic pressures. Prior to conducting the caving experiment proposed as Phase IA, the expected stand-up time of the tunnel cannot be reliably predicted. It is expected that the roof of the tunnel face will not initially be stable enough to be self supporting. Consequently, the lining system employed must have the capability of being installed up to the tunnel face as it is advanced. The tunnel lining will be instrumented to determine the magnitude and orientation of stress levels experienced and the gas pressures developed around the lining. The instrumentation will ensure the safety of personnel by monitoring the adequacy of the lining design. Future tunnels will be able to utilize this information to design more cost effective, safe linings.

Equipment Adaptations: Based on Saline Creek experience and open pit operations in the Athabasca region, both abrasive wear and the sticky, gummy nature of the oil sands will present difficulties in the mining and handling of the oil sands. Consideration of these problems should be made in the selection and preparation of the equipment to be used in the experiment. It

is expected that required equipment modifications would be modest due to the limited excavation work proposed. However, useful information will be gained for application to future underground excavation projects.

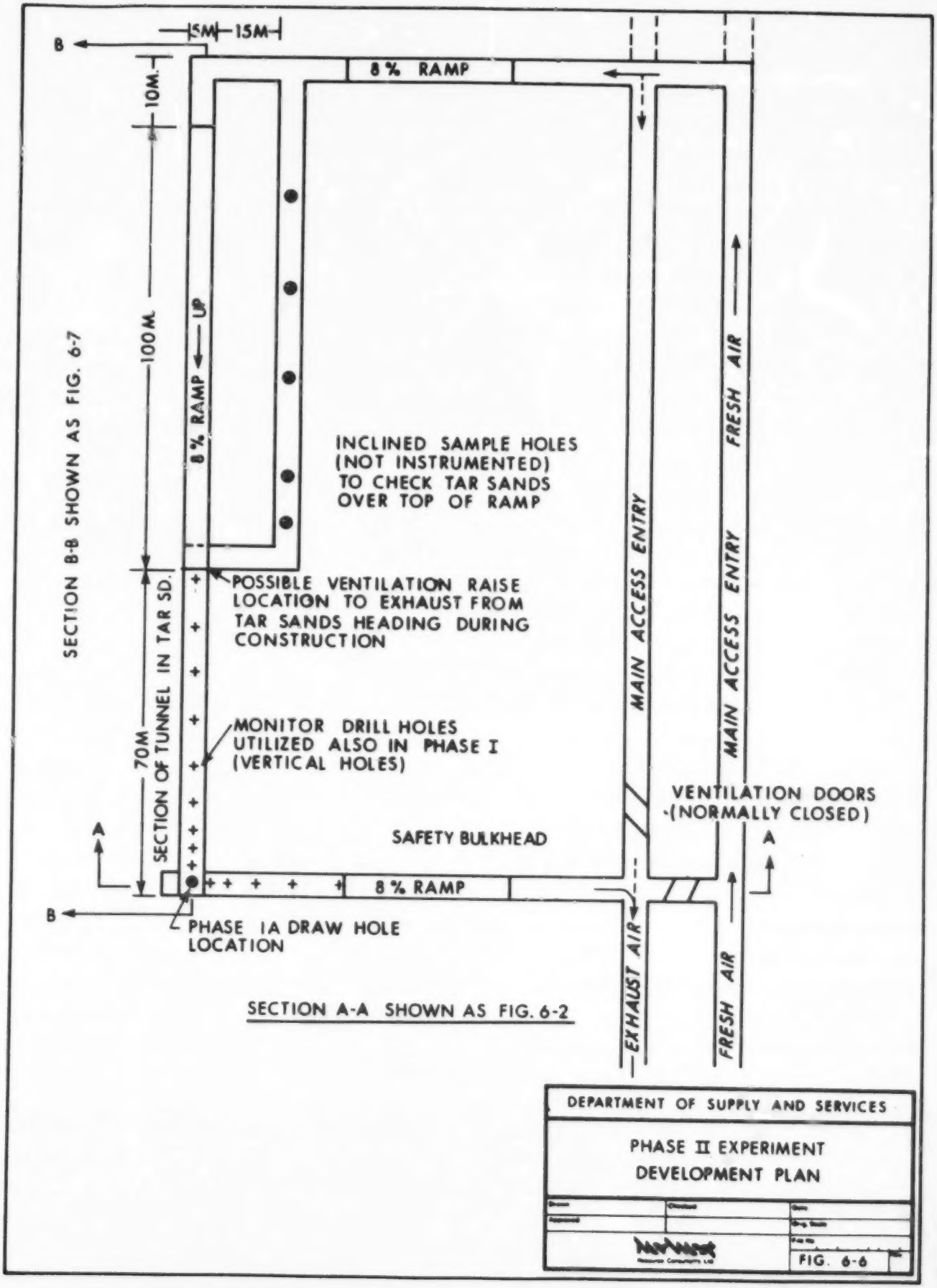
Geotechnical Observations: The cavability experiment will give an insight into the stand-up times, critical spans, effects of gas exsolution and area of influence of openings. These observation will be important for the final design of the tunneling experiment. The tunneling experiment, due to the larger size of the excavation, the different opening shape and orientation, will provide an additional opportunity to observe and measure these parameters under different conditions.

Future Base for Experiments: Once the test tunnel is excavated and observations completed, the tunnel would be available to conduct other experiments. Some of the applicable uses for this or other experimental tunnels are discussed under "Follow Up Research Work" (Section 8).

6.3.2 Location

It is proposed to locate the tunneling experiment as an extension of the area developed for the Phase IA Caving experiment. The proposed layout is shown in Figure 6-6 and has a number of advantages.

Safety: To ensure the tunnel does not intersect major sources of water or gas, drilling in advance of the oil sand tunnel will be mandatory. At present, it is not possible to safely drill from the exposed tunnel face. There is no acceptable method available to install blow out preventers which are entirely anchored in oil sand. Consequently, advance drilling must be conducted from the limestone formation where blow out preventers can be grouted into the limestone. It is proposed to develop the oil sand tunnel directly over the Phase IA test access tunnels. This area will have already been pre-drilled to check for major pockets of gas and water.


B
5M
15M
10M.
8 % RAMP
100M
8 % RAMP — UP
SECTION B-B SHOWN AS FIG. 6-7
INCLINED SAMPLE HOLES
(NOT INSTRUMENTED)
TO CHECK TAR SANDS
OVER TOP OF RAMP
POSSIBLE VENTILATION RAISE
LOCATION TO EXHAUST FROM
TAR SANDS HEADING DURING
CONSTRUCTION
MONITOR DRILL HOLES
UTILIZED ALSO IN PHASE I
(VERTICAL HOLES)
70M
SECTION OF TUNNEL IN TAR SD.
A
B
PHASE IA DRAW HOLE
LOCATION
SAFETY BULKHEAD
8 % RAMP
MAIN ACCESS ENTRY
FRESH AIR
MAIN ACCESS ENTRY
FRESH AIR
VENTILATION DOORS
(NORMALLY CLOSED)
A
EXHAUST AIR
FRESH AIR
SECTION A-A SHOWN AS FIG. 6-2
DEPARTMENT OF SUPPLY AND SERVICES
PHASE II EXPERIMENT
DEVELOPMENT PLAN
FIG. 6-6

Monitoring: The proposed tunnel location is in the area where geotechnical and stratigraphic information of the oil sands was obtained in Phase IA. The ready access to safe ground immediately below the proposed oil sand tunnel gives an excellent opportunity to use existing installed instrumentation and to install additional instrumentation if desired.

Minimizing of Costs: The costs of the experiment will be substantially reduced by utilizing the Phase IA test area. The following cost savings will be realized:

- the construction of major new test area access tunnels and safety bulkheads will be avoided.
- major power, communications services and ventilation will already be provided.
- the tunnel access in limestone for monitoring and pre-testing for hazards will be completed as a Phase IA cost.
- base geotechnical data of the oil sands will have already been obtained in Phase IA and some of the instrumentation will still be in place.
- if the completed oil sand tunnel extends to the caving experiment drawhole, flow-through ventilation will have been obtained without the expense of excavating a second ramp or raise through limestone.

Variable In Situ Conditions: As the tunnel is excavated, it will initially be in an undisturbed oil sand environment. As the tunnel is extended closer to the drawhole used in the Phase IA, the oil sand will have been de-stressed and gas pore pressures reduced. The horizontal area of influence from the caving experiment is expected to be limited and will be known in advance from Phase IA monitoring. This will be an opportunity to observe the effects on the tunneling process as the excavation proceeds from undisturbed oil sand material, through a transition zone into the fully de-stressed zone immediately adjacent to the drawhole. In addition, it will provide an opportunity to observe, first hand, the results of the caving experiment.

6.3.3 Staging and Access

The facilities and access requirements of the tunneling experiment are the same as discussed in the Phase I experiment proposal. All of the equipment used during Phase I will continue to be utilized. In addition to the equipment already underground, a road header mining machine will be required for tunneling in the oil sand. Shaft dimensions need to be considered for both the road header and its power supply equipment.

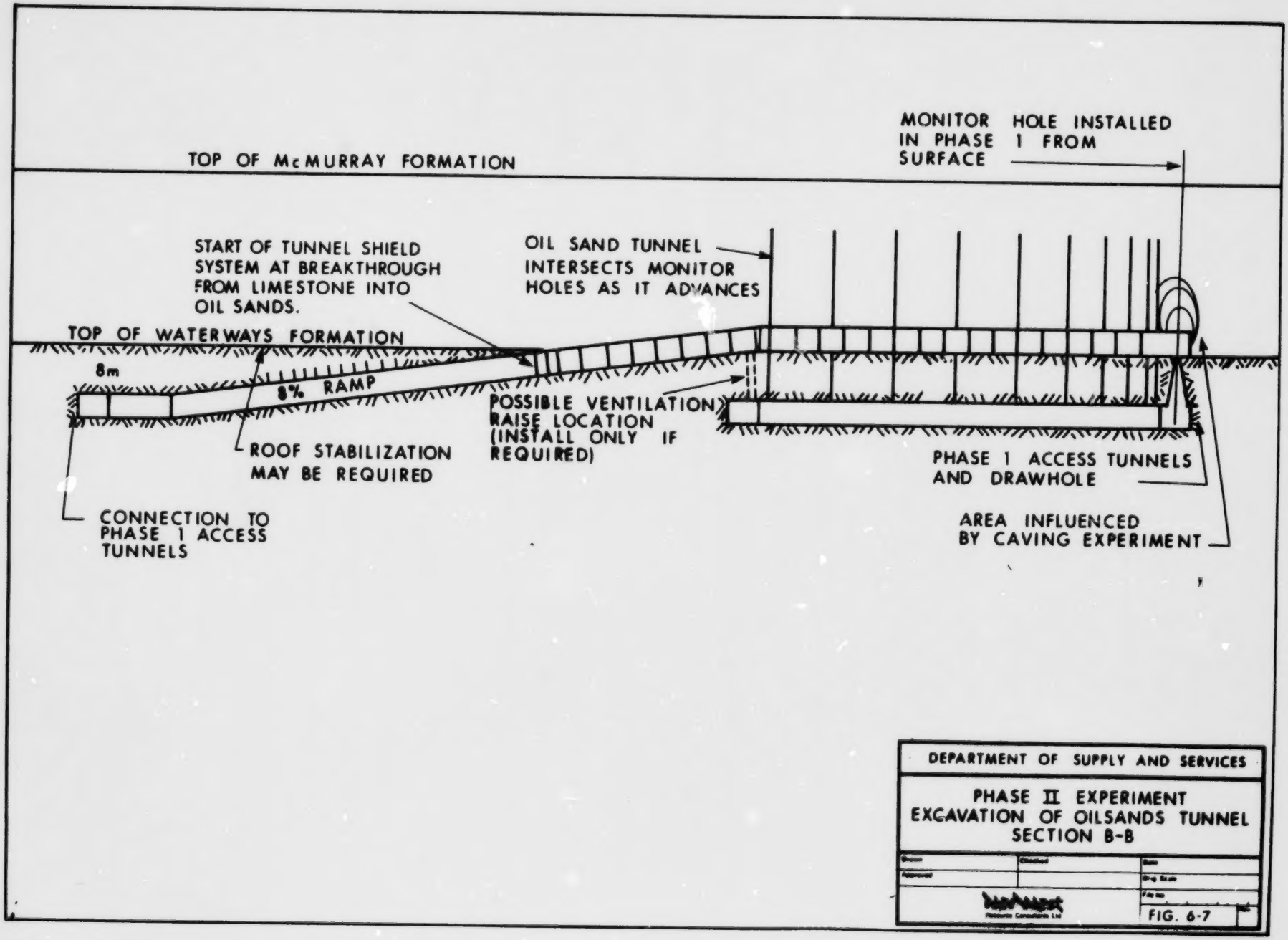
The tunnels, liners and mining equipment must be of a suitable size for lowering underground and transporting to the test site. The L.H.D. used for oil sands disposal should be equipped with a quick change attachment to allow its bucket to be replaced by forks for materials handling duties.

6.3.4 Experiment Description

The Phase IA caving experiment is expected to provide enough information on oil sand behavior to be able to confidently proceed with the proposed oil sand tunneling phase since the spalling of oil sands exposed to a free face will have been observed. Measurements of the rate of gas exsolution and how it varies with time will have been monitored. Indications of the area of influence of the caving conducted in the Phase IA will be known. All of these observations will give a good indication of conditions which will be experienced in excavating the tunnel.

The development of the tunnel in oil sands will consist of three steps:

Step 1 - Oil Sand Access: As shown in Figure 6-6 the Phase II development is accessed as an extension of Phase I development. Development will consist of 30 m of horizontal tunnel in limestone and then approximately 100 m of ramp in limestone (8% gradient) providing access up to the base of the McMurray formation (Figure 6-7). This layout minimizes the development cost and provides the opportunity for improved ventilation. At


MONITOR HOLE INSTALLED IN PHASE 1 FROM SURFACE
TOP OF McMURRAY FORMATION
START OF TUNNEL SHIELD SYSTEM AT BREAKTHROUGH FROM LIMESTONE INTO OIL SANDS.
OIL SAND TUNNEL INTERSECTS MONITOR HOLES AS IT ADVANCES
TOP OF WATERWAYS FORMATION
8m
8% RAMP
POSSIBLE VENTILATION RAISE LOCATION (INSTALL ONLY IF REQUIRED)
ROOF STABILIZATION MAY BE REQUIRED
PHASE 1 ACCESS TUNNELS AND DRAWHOLE
CONNECTION TO PHASE 1 ACCESS TUNNELS
AREA INFLUENCED BY CAVING EXPERIMENT

DEPARTMENT OF SUPPLY AND SERVICES

PHASE II EXPERIMENT
EXCAVATION OF OILSANDS TUNNEL
SECTION B-B

FIG. 6-7

the top of the ramp a ventilation raise may be connected to the Phase I access entry below if required. As the excavation of the ramp proceeds, the limestone encountered will change from a massive to an argillaceous, brecciated limestone. Back support via roof bolting and possibly shotcrete may be required. Test drilling should be conducted to determine the competency of the ground ahead and to test for any significant water or gas inflows. The test drilling will also establish the precise location that the break through into oil sands will occur.

Step 2 - Heading Development in Oil Sands: The critical stage of the development will occur at the point where the ramp nears the limestone/oil sand contact. At this point the thickness of limestone overhead thins in a wedge shape and weakens so that the limestone no longer forms a competent roof. The detailed method of establishing a safe breakthrough requires additional consideration. It is at this location that installation of a suitable tunnel lining is required. Consultation with experienced tunneling contractors and shield manufacturers should occur during the detailed design stage. Information gained during the Phase IA caving experiment may result in significant alterations to the final tunneling plans.

Step 3 - Tunneling in Oil Sands: It is proposed that a road header mining machine be utilized for excavating the oil sands. The cutter head should be specially designed to resist the abrasive nature of the silica rich sands. Hard surfacing of the type used on feeder-breaker rolls at Syncrude may be applicable. Problems of sticking and plugging of the gathering head and conveyor are expected. Discussion with the manufacturer of the equipment selected may overcome some of the more difficult problems. Oil sands transport to the shaft should be by L.H.D. An ejector type bucket would help overcome some of the sticking problems expected when trying to dump the oil sands. These problems, while slowing the excavation progress, will not prevent the success of the project.

The stand-up time and spalling phenomena of the oil sands will be the key material properties that influence the relative ease or difficulty of the tunneling process. Continuity of the experimental program will likely dictate that the tunnel liner design be completed prior to the Phase IA caving experiment. Due to lack of definitive information, the liner design must be conservative in strength and allow for installation at the tunnel face. Saline Creek tunnel experience clearly demonstrates that shields or some other material must form the operating base for the mining machine and the haulage equipment. The oil sands are not a suitable base for heavy moving or vibrating equipment. As noted earlier, the shields should be designed to be gas permeable. This will prevent the build up of gas pressure around the shield system. Based on drill hole data and results from the Phase IA caving experiment the expected flow rates of gas can be calculated. This will need to be used to calculate a safe fresh air flow rate to be established for the length of tunnel planned.

Continuous explosive gas monitors used in the initial experiments will be essential during tunnel excavation.

As the tunnel is advanced, previously installed monitoring equipment will measure the effects of the advancing tunnel. Additional instrumentation installed from the same locations but angled to miss the edges of the excavation can be used for on-going monitoring of the sand behavior, during and after excavation is complete.

As the tunnel approaches the Phase IA drawhole, the in situ stresses and gas pressures are expected to be relieved. The effects on the oil sands behavior, such as stand-up time, will be observed. Once the draw hole location is reached, flow through ventilation will be possible; substantially improving air quality in the oil sands tunnel. Other types of follow-up work are proposed that could utilize both the Phase I and II tunnels.

Despite the aforementioned problems excavating a tunnel in oil sands, it is the authors opinion that, after initial release of in situ gas pressures, the oil sands will be relatively stable at this depth.

6.4 OBSERVATIONS

6.4.1 Introduction

The proposed observations to be made during the excavation of the draw hole are described in general terms in the following sections. It is expected that the final selection of instrumentation to be used will be established during the detailed design of the proposed experiments. The emphasis should be on proven, simple and reliable methods of measurement and instrumentation. This is essential since the primary purpose of the mining experiment is to establish the behaviour of the oilsand adjacent to a cavity. Research and development of instrumentation for measuring the in situ behaviour of oil sand should remain a secondary objective.

In addition, it is essential that the program of observations be as flexible as possible, in view of the many uncertainties with regard to the behaviour of the oil sands at this depth. It is envisaged that initially, only a portion of the possible instrumentation would be installed. Additional instrumentation would be installed as the draw hole is excavated and would be tailored to the observed behaviour of the oil sands.

Finally, the amount of instrumentation must be controlled, with the view that a few, simple measurements are usually preferable to a large amount of data which cannot be properly analysed and which often tends to obscure the key experimental observations.

The program of observations will involve the following major areas:

- Formation Properties
- Deformation

- Cavity Geometry
- Formation Permeability
- Fluid Pressure
- In Situ Stresses
- Gas Monitoring
- Materials Handling

6.4.2 Formation Properties

It will be important to establish, as completely as possible, the properties of the oil sand formation, prior to starting the experiment. This data is necessary so that the results of the experiment can be extrapolated to other oil sand deposits at different depths. The properties of the oil sand would be obtained from laboratory analyses on core recovered from test holes drilled in the vicinity of the proposed draw hole. These properties include:

- bitumen, water and gas contents
- grain size distribution curves
- in situ density and core density
- geological discontinuities (bedding planes, fractures, joints)
- any inter-relationship of these properties

6.4.3 Cavity Geometry

The geometry and stability of the walls of the cavity will be monitored as the draw hole is excavated. This information is extremely important since the stand up time of the oil sand must be established before suitable tunneling or mining techniques in the oilsand can be established. The method used to monitor the geometry of the cavity will depend on the stability of the walls of the cavity. During the initial stages of the experiment, when the draw hole is less than 150 mm in diameter, it is expected that convergence of the oilsand around the draw hole could be best monitored through the use of a borehole caliper. Successive measurements would be made to determine the behavior of the oil sand as a function of time.

Once the cavity has been been enlarged to a diameter of 0.9 metres (Stage 2 of Phase 1B), it is expected that observations on the behaviour of the oil sands could be made using a borehole camera. If the walls of the cavity remain stable, then the geometry of the cavity could be measured using sonar techniques, similar to the method used to monitor the shape of underground storage caverns constructed at depth in the Prairie Evaporites by solution mining.

The volume of the cavity will also be monitored by measuring the weight of the material removed from the excavation. This approach may be the only feasible method of deducing the volume of the cavity if the oil sand is highly unstable.

6.4.4 Formation Permeability

One of the most important objectives of the experiment is to establish the radius to which the permeability of the formation is increased as a result of the excavation of a cavity in the oil sand. This information is required in order to evaluate the feasibility of using mining techniques to enhance the in situ recovery of bitumen from the formation.

It is anticipated that the most suitable method of measuring changes in permeability of the formation adjacent to the draw hole will be through the use of air injection testing in boreholes drilled at various distances from the centre line of the draw hole. This method of measuring in situ permeability was developed by Canmet and was used successfully to measure changes in permeability adjacent to the walls of Saline Creek Tunnel. It is important to note that air injection tests do not provide a quantitative measurement of in situ permeability, however, the data does provide a reasonable indication of changes in the permeability.

Another method of measuring changes in formation permeability would be through the use of borehole densometers. The densometer can be used to

measure changes in formation density in boreholes drilled at various distances from the draw hole. This method can be used to provide a good indication of average changes in permeability, provided a good relationship between in situ density and permeability has been established. Such a relationship could be determined through a series of laboratory permeability tests on recovered oil sand core.

6.4.5 Fluid Pressures

Observations on fluid pressures would also be made during the course of the experiment. These observations are important for the following reasons:

- The in situ fluid pressure and rate at which fluid pressures dissipate around a cavity are known to be one of the key parameters governing the behaviour of the oil sand.
- Changes in fluid presure adjacent to the cavity will provide an indication of the radius of influence of the cavity and its effect on formation permeability.

Formation fluid pressures would be monitored through the use of pneumatic piezometers installed in test holes placed at various distances from the centreline of the proposed draw hole. Pneumatic piezometers have been used successfully to measure fluid essures in the oil sands in the past. The piezometers must be installed prior to commencement of the excavation of the draw hole. They must be sealed into the test hole and pressures must be monitored until the fluid pressure recovers to the original in situ pressure prior to starting excavation of the draw hole.

6.4.6 Deformation

Deformation adjacent to the cavity is important in that it provides a more complete understanding of the behaviour of the oil sand and can be used to establish design loads on tunnel supports. The measurement of deformations

adjacent to the proposed cavity is difficult because of the configuration of the proposed experiment. Consideration should be given to the use of borehole inclinometers and extensometers in order to monitor deformation during various stages of the experiment.

6.4.7 In Situ Stresses

In situ stresses in the oil sands, coupled with geological discontinuities, will control the shape of the unsupported cavity. In situ stress will also control the fracture pattern resulting from high pressure steam injection, should it be undertaken as part of an in situ bitumen recovery process.

In situ stresses have been successfully measured at depth of up to 15 meters below ground surface in the oil sands using the self boring pressuremeter. It is anticipated that the equipment could be readily modified for use underground. In addition to the measurement of in situ stresses, the data from the pressuremeter can be used to establish the deformation moduli for the oil sand.

6.4.8 Gas Monitoring

Monitoring would be carried out continuously during the experiment in order to determine the concentration and types of gases released into the working area during excavation of the draw hole. Such monitoring is essential to ensure the safety of the miners during the experiment. In addition, the data can be used to establish ventilation requirements for future tunneling into the oil sands. Consideration should be given to sealing off the experimental area and monitoring the build up of gases in the confined area with time.

6.4.9 Materials Handling

General observations associated with drilling and handling the oil sands would be recorded during the course of the experiment. These observation will be of value in establishing the most suitable methods of tunneling in the oil sands and handling mine muck. The observations would include:

- drilling rates and associated difficulties with drilling in the oil sands
- trafficability
- digging and mucking characteristics.

6.5 EVALUATION OF RESULTS

The results from the various observations would be evaluated in the field as the work progresses and the experiment and program of observations would be modified, based on the field evaluation.

After the experiment has been completed, all of the observations would be reviewed, and summarized in a data report. A preliminary analysis and evaluation of the results would be included in the data report.

It may be warranted to undertake a comprehensive analysis of the data, using the field observations to check the predictive capability of existing computer programs to analyse the deformation behaviour of oil sand adjacent to cavities. Such programs can then be used to extrapolate the observed behaviour of the oil sands to cavities of different dimensions and/or at different depths in the oil sands.

A decision as to whether or not a comprehensive analysis of the data is warranted cannot be made until after the experiment has been completed and the observations have been evaluated in a preliminary way. For example, if the oil sand does not behave as a continuum (as is assumed in current

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PROJECT SCHEDULE PHASES 1A – 1B

FIG. 6-8

ACTIVITY	— CALENDER MONTHS —																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
AOSTRA APPROVAL (PRELIMARY)	*																	
GOVERNMENT APPROVALS	▒	▒	▒															
MOBILIZE MANAGEMENT TEAM	▒																	
DETAILED ENGINEERING PHASE 1A		▒	▒															
FINAL AOSTRA UTF APPROVAL			*															
TENDER AND AWARD CONTRACTS				▒	▒													
MOBILIZATION					▒													
TEST AREA ACCESS																		
• TUNNEL DEVELOPMENT						▒	▒	▒	▒	▒								
PHASE 1A RESEARCH																		
SURFACE ACTIVITIES																		
• TEST HOLE FROM SURFACE		▒																
• INSTALL INSTRUMENTATION			▒															
• INSTALL SUBSIDENCE MONITORS											▒							
UNDERGROUND ACTIVITIES																		
• DRILL MONITORING HOLES AND INSTALL INSTRUMENTATION											▒							
• STAGE 1 DRILLING AND MONITORING INITIAL DRILLHOLE (100 - 150 mm)												▒						
• STAGE 2 DRILLING HOLES FOR STAGES 2 – 5												▒	▒					
• BLAST AND MONITOR STAGE 2 (0·9 m HOLE)													▒	▒				
• BLAST AND MONITOR STAGE 3 (2·0m HOLE)														▒	▒			
• BLAST AND MONITOR STAGE 4 (3·0m HOLE)															▒	▒		
• BLAST AND MONITOR STAGE 5 (4·0m HOLE)																▒	▒	
REVIEW RESULTS OF PHASE 1A																▒	▒	
PHASE 1B RESEARCH																		
• DRILL AND BLAST INITIAL FAN.																	▒	
• MONITOR BLAST AREA.																	▒	▒

Nichwest Resource Consultants Ltd

PROJECT SCHEDULE – PHASE II

FIG. 6-9

ACTIVITY	— CALENDER MONTHS —																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
PHASE II (TUNNEL IN OILSANDS)																		
• DETAILED ENGINEERING																		
• AOSTRA UTF APPROVAL			*															
• PRE DRILL AREA FOR GAS AND WATER																		
• INSTALL MONITORING INSTRUMENT																		
• TENDER AND AWARD CONTRACTS																		
• EXTEND HORIZONTAL TUNNEL (30m)																		
• DEVELOP RAMP AT 8% INTO OILSANDS (100m)																		
• ADVANCE TUNNEL WITH SHIELDS																		
• MONITORING											ONGOING							
• REVIEW RESULTS OF PHASE II																		

computer deformation analysis programs) then a comprehensive analysis of the field data would probably not be worthwhile.

6.6 PROPOSED TIMING AND SCHEDULE

A preliminary schedule of activities has been prepared to represent Phase I and Phase II of the proposed experiment as two separate entities. These are shown on Figures 6-8 and 6-9 respectively. Reference to Section 6.2 is recommended for any clarification of tasks.

An undetermined period of time has been left open for review of Phase I data by industry experts before commencing the Phase II experiment.

Due to the lack of experience in the behaviour of the material to be excavated several assumptions have been made. This has resulted in a conservative estimate of allocated time for each activity.

Additional follow-up work has not been scheduled at this time and should be looked at further after evaluating Phase I and II results.

6.7 COST ESTIMATES

The estimated cost for the experiment is based on the following general assumptions:

(1) The UTF site will be used for the experiment and AOSTRA will provide the necessary services to support the experimental project at a "users fee". This has been estimated at 15% of the value of the project and will require discussioon with AOSTRA if the experiment is to be initiated.

(2) All mining activity will be performed by a contractor who will supply the necessary equipment, personnel and materials.

(2) The project staff, supported by consultants as necessary, will provide direction, monitor technical results of the work, compile and interpret data and prepare the final report.

Separate cost estimates have been prepared for Phase I, (Table 6-1), and Phase II, (Table 6-2) of the experimental project. Based on these cost estimates and the 15% "user fee" the AOSTRA charge would amount to $570,000 for a total project cost of $4,370,000.

The estimates should be considered as order of magnitude costs since at this point there are many unknowns which cannot be quantified with any degree of certainty. For a more accurate cost estimate the following will have to be undertaken:

(1) A higher level of engineering and design will have to be provided for both Phases I and II but with particular emphasis on Phase II.

(2) Discussions will have to be initiated with AOSTRA to establish firstly the level of support required from the existing UTF personnel and facilities and then, to determine an acceptable "user fee" for these services. A detailed operating plan for the experimental project has to be developed prior to these discussions if they are to be meaningful.

(3) Concurrently with Task 2, discussions will have to be conducted with contractors, consultants and equipment suppliers with the objective of refining the cost estimate with a more definite scope of work.

6.7.1 Discussion of Cost Estimates

(1) A 6 man project staff is used in the costing at $5,000/man month. This figure includes the basic salary, fringe benefits and all allowances. The project staff is supported by consultants for specific items of work such as regulatory approvals, detailed design, installation of

TABLE 6-1

PHASE I COST ESTIMATE

(A) PRELIMINARY WORK	
• Regulatory approvals	$25,000
• Detailed design Phase I	75,000
• AOSTRA discussions and presentations	15,000
• Preparation of tenders and award	35,000
• Mobilization and demobilization	150,000
Sub total	$300,000
(B) TEST AREA ACCESS	
• Mine development	800,000
Sub total	$800,000
(C) PHASE IA RESEARCH SURFACE WORK	
• Surface test hole	25,000
• Instrumentation	30,000
• Subsidence monitors	20,000
Sub total	$75,000
(D) PHASE IA RESEARCH UNDERGROUND WORK	
• Drill and install instrumentation	55,000
• Perform stage 1 to 5 experiments	65,000
Sub total	$120,000
(E) DOCUMENTATION OF RESULTS PHASE IA	
• Assemble and interpret data	20,000
• Prepare report	10,000
Sub total	$30,000

TABLE 6-1 (Cont'd)

(F) PHASE IB RESEARCH UNDERGROUND WORK	
• Drill and blast fan	15,000
• Reinstall instrumentation and monitor	75,000
Sub total	90,000
(G) DOCUMENTATION OF RESULTS PHASE IB	
• Assemble and interpret data	20,000
• Prepare report	10,000
Sub total	30,000
(H) FULL PHASE I DOCUMENTATION	
• Integrate and interpret Phases IA and IB	10,000
• Prepare Phase I report	10,000
Sub total	20,000
Sub-total Phase I Cost Estimate	$1,365,000
Contingency 20%	273,000
Sub total	$1,638,000
Project Staff (6) for 17 months	510,000
TOTAL PHASE I COST ESTIMATE	$2,148,000
USE	$2,200,000

TABLE 6-2

PHASE II COST ESTIMATES

(A) PRELIMINARY WORK	
• Detailed design stage	100,000
• AOSTRA discussions	5,000
• Preparation of tenders and award	35,000
• Mobilization and demobilization	80,000
Sub total	$220,000
(B) DEVELOPMENT AND RESEARCH	
• Mine development	640,000
• Pre-drill area for water and gas	5,000
• Install monitors	100,000
• Monitor (6 mo.)	75,000
Sub total	$820,000
(C) DOCUMENTATION	
• Assemble and interpret data	40,000
• Prepare Phase II report	10,000
Sub total	$50,000
Sub-total Phase II Cost Estimate	1,090,000
Contingency 20%	218,000
Sub total	1,308,000
Project Staff (6) for 10 months	300,000
TOTAL PHASE II COST ESTIMATE	$1,608,000
USE	$1,600,000

instrumentation, data interpretation, etc. The consultants are costed at $10,000/man month.

(2) Mine development for Phase I of the experiment is costed at an estimated all inclusive contract price of $2,000/metre of advance. The oil sands mine development in Phase II is estimated to cost $4,000/metre because it is in more difficult ground, is advanced at a slower rate and requires frequent disruption of mining work to allow the necessary technical data to be gathered.

(3) It may be possible to conduct the Phase I development, which in many respects is similar to the development at the UTF, in conjunction with existing larger contracts at the site and possibly obtain the benefits of lower unit costs. Although the site contractor may also be used for Phase II development, the work is much different than anything routinely done at the site. It will likely have to be contracted as a separate function and at a higher cost than the Phase I development.

(4) The AOSTRA "user fee" is unknown at this stage. It is assumed that it will cover the cost of surface support facilities such as the shop, warehouse, mine dry, first aid room and office facilities; underground services such as transportation of men and materials for other than the contracted development, safety inspections and monitoring, compressed air, water and power, ventilation and supervisory staff services for the experimental project.

(5) Instrumentation for monitoring the experiments has been estimated to cost $245,000.

6.8 OTHER CONSIDERATIONS

6.8.1 Patents

An extensive patent search was conducted after the proposed experiments had been developed in order to accurately predict whether any infringements on existing patents would apply if these studies took place. Although it is not the intention of the study to make any legal statements regarding these infringements it is the opinion of the authors that there are no patents which directly effect the proposed experiments.

A total of 38 separate patents were reviewed and are listed in Appendix B along with their respective abstracts as provided by the patent authorities. They were compiled from three comprehensive patent data bases and reflect all available patents relating to underground mining of oil sands using bulk extraction methods. This includes caving and blasting, hydraulic mining, and in situ techniques utilizing the shaft and tunnel concept. None of these appear to pertain to the proposed experimental studies. If, however, a commercial scheme were implemented which utilized bulk or partial extraction of oil sands a detailed analysis of the various patents would be required.

6.8.2 Regulatory Agencies

The mining of oil sands in Alberta from an underground facility is a relatively new concept. While some of the hazards are not well defined, there is sufficient knowledge of mining in hazardous locations to enable the work to be done safely. In recent years, legislators in Alberta have followed a worldwide trend in enacting a great deal of legislation in this area. Concerns of both the Division of Occupational Health and Safety and the Energy Resources Conservation Board must be addressed prior to implementation of the experiments.

The Occupational Health and Safety Act, Section 2, as amended to November, 1983, applies to this program. Section 2 of the act states that;

1) Every employer shall ensure, as far as it is reasonably practicable for him to do so, the health and safety of:
   (a) workers engaged in the work of that employer, and
   (b) those workers not engaged in the work of that employer but present at the work site at which that work is being carried out.

(2) Every worker shall, while engaged in an occupation:
   (a) take reasonable care to protect the health and safety of himself and of other workers present while he is working, and
   (b) co-operate with his employer for the purposes of protecting the health and safety of:
      (i) other workers engaged in the work of the employer, and
      (ii) other workers not engaged in the work of that employer but present at the work site at which that work is being carried out.

(3) Every supplier shall ensure, as far as it is reasonably practicable for him to do so, that any tool, appliance or equipment that he supplies:
   (a) is in safe operating condition, and
   (b) complies with the standards, if any, prescribed or adopted by the regulations.

(4) Every principal contractor engaged in a project shall ensure, as far as it is reasonably practicable for him to do so, that every employer and every worker performing work in respect of that project complies with this Act and the regulations.

While the Occupational Health and Safety Act and Regulations apply to the facility, there are no laws or regulations that specifically apply to underground oil sands mining. As some of the anticipated hazards are similar to

underground coal mines, officials of the Occupational Health and Safety Division have stated that the requirements of the Coal Mines Safety Act and Regulations should be used as guidelines for determining the safe operating procedures and standards for underground oil sands test facilities. It is apparent that regulations will be enacted in future bringing the Coal Mine Safety Act and Regulations and the Quarries Regulation Act and Regulations under the umbrella of the Occupational Health and Safety Act. This process has commenced piecemeal with Coal Dust Regulation, Explosives Safety Regulation, Noise Regulation etc.

The Division of Occupational Health and Safety is responsible for:

(a) drafting safety related legislation and guidelines for codes of practice.

(b) inspecting work places at appropriate intervals to assure compliance with safety regulations and codes of practice, to issue compliance orders and recommend sanctions against offenders when required.

(c) investigating serious accidents and hazardous occurences, issuing reports thereon to industry, and where required, making recommendations for revision of safety legislation or codes of practice.

(d) approving designs for mine sites and processing plants with respect to matters bearing on workers health and safety.

(e) setting standards for certification of equipment, reviewing design specifications and operating procedures, and requiring field tests to ensure compliance with standards.

(f) setting standards for the training and certification of personnel and encouraging safety education and training of mine personnel in mine rescue, fire fighting and special safety procedures.

(g) developing and implementing a system for compiling and disseminating accident and illness statistics.

(h) identifying areas requiring research and development to reduce the potential for injuries and ill health and fostering such research.

The Energy Resources Conservation Board administers the Energy Resources Conservation Act, the Oil and Gas Conservation Act and related regulations and develops guidelines for the development of coal and oil sands resources in Alberta.

The board is responsible for:

(a) the legal mandate assigned to it by The Coal Mines Safety Act and The Quarries Regulation Act until these responsibilities are replaced by legislation under The Occupational Health and Safety Act

(b) ensuring that safe and efficient practices are observed in the exploration for, mining, storing, processing and transporting of coal

(c) drafting legislation and guidelines for the development and conservation of coal and oil sands resources

(d) reviewing applications for exploration and development of coal and oil sands resources under relevant legislation and guidelines and, when required, conducting public hearings into the suitability of proposed developments

(e) issuing orders relating to development and/or abandonment of coal and oil sands mines and processing plants

(f) inspecting exploration projects, experimental schemes, mine sites and processing plants at least once every three months to assure compliance with Board regulations and orders

(g) inquiring into events which have affected resource conservation, and, when necessary, issuing reports, codes of practice, informational letters or interim directives to industry

(h) co-ordinating, or serving as a liaison between, industry and government departments and agencies with interests in coal and oil sands developments, and

(i) receiving and assimilating exploration and production data in order to independently assess the resource and promote orderly development by dissemination of information.

SECTION 7

HEALTH AND SAFETY

SECTION 7

HEALTH AND SAFETY

7.1 INTRODUCTION

Health and Safety in the workplace are an important part of any mine operation. Safe underground activities, where accident injuries and health hazards of both operating and investigating staff are minimized, is most successfully attained if Health and Safety are included at the inception of project planning. This is particularly true of a project which addresses underground, experimental or investigative extraction of oil sand. In the first place there is little previous Canadian experience of mining in, or in close proximity to, oil sands. The experience of sinking a test shaft in oil sand at the GCOS open pit operation in 1963 (Hardy, Scott, 1978) is enough to show that careful forethought and caution must be added to conventional mining experience. In the second place, an investigative project, by its very nature, frequently attempts to carry out unusual tasks without the benefit of previous relevant experience.

Every aspect of each stage of underground oil sands investigative trials and testing procedures, must be carefully analyzed to identify potential accidents or health hazards resulting from equipment and apparatus which is to be used or from the natural surroundings. In short, a detailed hazard analysis should be included as part of the planning procedure for investigative projects. Since the specific equipment, procedure and natural surroundings for the tests outlined in the report are not fully defined the following comments are necessarily general but highlight some important areas of safety and health related to oil sands, which should receive special attention.

7.2 RESPIRABLE ATMOSPHERE

7.2.1 Gas Emission

Gases which can be expected underground are, for the most part, those which occur naturally in the oil sand and surrounding strata. Measurements of the gas content in the oil sand, using the "lost gas" technique, do not produce totally reliable results, but indicate that the gas content is unlikely to be greater than 400 cm^3/kg of oil sand.

Analyses show the constitution of the oil sand gas to be in the following approximate proportions:

CH_4, Methane	78.0%
CO_2, Carbon Dioxide	20.9%
C_2H_6, Ethane	0.9%
CO, Carbon Monoxide	0.2%
	100.0%

Analyses to date have not detected measurable quantities of hydrogen sulphide (H_2S) but it should be assumed that this gas may be encountered in small but potentially dangerous concentrations.

For practical purposes the ethane and methane can be regarded as one flammable gas. The presence of this gas will necessitate all electrical equipment to be certified as permissible and acceptable to the Occupation Health and Safety - Mines Inspection Branch, for use in locations potentially hazardous by reason of flammable gas.

7.2.2 Ventilation

The underground gases will be rendered safe by providing good ventilation air flows to dilute and remove them. The highest gas emission should be expected at the face of an advancing tunnel in oil sand.

Experience and tests have shown that the gases are held in solution in the water and bitumen of the oil sand. As soon as the confining pressures are released, these gases come out of the solution very rapidly.

It is likely that, up to 40% of the total gas content could be replaced in the first 15 to 20 minutes. This means that a tunnel being driven in oil sand could emit up to 2.5 m^3/min of gas. An auxilary ventilation system delivering 6 m^3/s of air to the face should be capable of reducing the concentrations of gas in the tunnel atmosphere to safe, and acceptable levels. For example:

- oxygen level would be above the required minimum of 18 KPa partial pressure.

- flammable gases below 0.5%.

- carbon monoxide well below the 50ppm limit for an 8 hour exposure.

- carbon dioxide well below 5000 ppm for an 8 hour exposure.

Tunnels or drill holes put in from underground may make contact with other boreholes which have contacted or passed through the oil sands. In these boreholes hydrogen sulphide, other gases, or quantities of water, if suddenly released, could constitute a danger. Wherever possible these boreholes should be cemented up as soon as possible. Where they remain open or there is a

possibility that complete cementing was not attained then extra caution should be exercised as their location is approached.

7.2.3 Monitoring

Gas concentrations, air flow, auxiliary fan systems and oxygen content of the underground project sites should be closely monitored.

The monitoring system should not only record the concentrations of the different gases but should also provide audible and visual alarms to the people at the project site if pre-set safety limits are exceeded. It will be advantageous and perhaps required, to have monitoring devices which interface with the monitoring system planned for the facility.

7.2.4 Respiratory Apparatus

As an additional safety measure, project planners should arrange to provide caches of self contained oxygen self rescuers at underground testing sites and oranize training in their use.

There should also be in place pre-arranged emergency site evacuation programs in the event that there are sudden inflows of gases or gas laden water, into the project sites.

7.3 CONTACTABLE SUBSTANCES

7.3.1 Underground Water

Water in the Devonian limestone is known to contain natural salts in solution, for example sodium and calcium chloride, in amounts sufficient to render water saline and undrinkable, (see Table 12 in Appendix A). However, apart from any corrosive effects on equipment it is not perceived as a health hazard with the exception that some individuals might be prone to skin

rashes or other skin problems if exposed to the water for extended periods. In the kind of work proposed it will be difficult to avoid contact completely but the following steps might be taken:

(a) Analyze site specific water samples to seek the presence of potentially harmful salts or metals.
(b) Screen out personnel known to be susceptible to skin problems.
(c) Provide protective wear such as oilskin "slickers" and water proof gloves.

It is beyond the scope of this report to assess the risk of poisoning as a result of the small quantities of certain metals in the water (for example Nickel and Vanadium).

The consultants suggest that site specific water samples should be tested to determine whether in fact there is need for added precautionary measures.

7.3.2. Bitumen and Oil Sand

Experience in Alberta's open-pit oil sand mining operations and processing plants has not revealed injurious effects on the health of workers dealing with crude oil sand on a daily basis. There are no indications that bitumen presents a significant health risk as a carcinogen to workers in operations where bitumn is mined and processed. However, there is ongoing research in this area by AOSTRA funded, Research Projects. For example:

(a) Mr. E. Peake, U of C, is assessing the environmental hazards and health risks that might arise from carcinogenic components that could be generated during fire flood production from oil sands.

(b) The Carcinogen Testing Laboratory of B.C. Cancer Foundation is conducting studies related to genotoxicity testing of oil sands process steams and related materials. The entire study is aimed at developing a system for making human carcinogenic risk assessments.

More direct and practical concerns related to bitumen and oil sands are the unpleasant working conditions which can arise.

Firstly, it is likely that gloves will be required to keep the skin of the hands protected from the "sticky" bitumen and the highly abrasive sand.

Secondly, worker's wet suits may become coated with bitumen and sand making them uncomfortable to wear; constant replacement of suits will be an added cost item. Some workers may find the smell of the bitumen very disagreeable.

Project plans should anticipate showering facilities and storing clean and dirty clothes in the "dry". It is suggested that suitable cleaning soaps or barrier creams should be provided and that arrangements be made for cleaning of protective clothing on a daily basis. In the underground work places, operating procedures should include high standards of job-site cleanliness.

7.4 GROUND CONTROL

7.4.1 In the Limestone

Support of roof and sides in the limestone tunnels should not present any special problems peculiar to mining under oil sands. Nevertheless, project planning should develop specific support plans based on site specific stratigraphical and geotechnical information. It will be necessary to produce a Code of Practice for support of roof and sides that will specify:

(a) the type and density of support.

(b) the method of installing the support in a manner compatible with tunneling or testing activities.
(c) the program for testing and maintaining the supports, and
(d) when and how support re-inforcement will be installed.

The primary tunneling horizon will be in the Devonian limestone, although as described in Section 6, the proposed experiments will ultimately require tunnelling in oil sand. For tunnels in limestone, geotechnical evaluations have indicated that 5 m wide by 4 m high openings can be supported, at modest cost, by roof bolts supplemented by wire mesh and/or shotcreting in zones of weaker strata. This is also adequate for the operation of mobile equipment.

Although roof bolts, wire mesh, and/or shotcreting can be used in the original tunnel drivage there could be special areas where extra steel arch or steel frame supports will be needed. These areas should be identified during the detailed experiment design.

7.4.2 In Oil Sand

The support required for oil sand tunnels is extremely difficult to predict. The behaviour of the oil sand during excavation at depth is not known and tunneling and support of the tunnel should be approached with caution; a fully lined, circular support, might be found necessary.

As described in Section 6.3.4 some information will have been gained from testing before a tunnel in the oil sand is driven and all available data should be examined carefully before final plans are made to break into the base of the oil sands. The actual breakthrough will have been preceded by drilling, however, in order to ensure a safe operation, the first opening into oil sands should meet certain requirements:

(a) a small opening should be developed initially.
(b) the operator should be supervised by experienced mining personnel.

(c) contingency plans should be ready in the event of:
  (i) high rates of gas emission
  (ii) high inflows of water
  (iii) inflows of oil sand

(d) and finally, provision should be made for additional ground support in the limestone tunnel as it approaches the point of contact with the oil sand.

The use of shotcrete both as a means of support and as a means of sealing off the tunnel sides against gas flow and water flow should be kept in mind. Project planning should provide for shotcreting equipment and materials to be available for use in case emergency sealing has to be started quickly.

7.5 DRILLING AND BLASTING

7.5.1 Drilling

There are three types of drilling envisaged in the project:

- Drilling to penetrate the oil sands
- Drilling to locate measuring instruments
- Drilling of blast holes

Many of these boreholes will pass from the limestone tunnel up into the oil sands in an unknown or unproved area. The possibility of aquifer in the base of the oil sands must be considered a potential danger unless previous holes have shown the area to be safe.

These aquifers can carry large flows of water at hydrostatic pressure which, if not controlled at all times could create very hazardous circumstances and incur extremely costly remedial actions.

Where the ground is unproven, drilling procedures must employ mining type stuffing boxes attached to standpipes cemented in the collar of the hole to

act as a "blow-out preventor". This measure should be backed up by the pre-preparation of ditches, sumps and adequate pumping capacity. It should not be forgotten that any water flows of this type could also release disolved gases so that additional back-up ventilation air quantities should be available.

Safe procedures must be devised for installing up-hole instrumentation. The placing of the instruments must be done safely to prevent the danger of the instrument falling out of the hole. Fast acting resins might be a suitable means of safely securing the up-hole instruments.

All the usual safety procedures for underground drilling will apply with special attention given to drill steels falling out of holes and of oil sand squeezing into or being extruded from holes.

7.5.2 Blasting

The experimental procedures described in this report call for blasting, in long up-holes drilled into the oil sands, to create and enlarge cavities in the oil sand. Approved explosives and blasting equipment will undoubtedly be required by Provincial Safety and Health Authorities. A procedure for blasting safely into an unventilated cavity in oil sands, where there is likely to be an accumulation of flammable gas, will have to be carefully planned. The procedure will need the approval of the Mines Inspection Branch before it can be implemented.

Two measures are proposed which might be considered as a means to achieve safe blasting of oil sand cavities. They are:

(a) the use of nitrogen and
(b) the use of water enclosed explosives.

Nitrogen injected into the cavity might provide a means of displacing any flammable gases and replacing them with the non-explosive, inert, nitrogen.

The blast hole can be lined with a thin walled plastic tube, sealed at its upper end. With an explosive charge placed inside the tube, the tube can be filled with water and sealed with a plug at the base of the oil sand. The charge can then be detonated while totally surrounded by water.

These measures should help to overcome the necessity of examining the cavity for gas before blasting and would minimize any danger of igniting bitumen.

7.6 OPERATIONAL SAFETY

7.6.1 Hazard Analysis

As each phase of the project is being planned, Hazard Analysis should be an integral part of the planning procedure. There should be an analysis of the general procedural plan followed by a detailed analysis of each physical task to be carried out including the equipment and tools that are to be employed. The hazards and risks to which persons will be exposed and the protective measures to be employed can then be drawn up. A review of relevant existing Safety Codes, Safety Acts and Regulations will be necessary to ensure:

(a) that all the hazards envisaged in these Codes and Regulations have been addressed, and

(b) that the proposed safety measures are compatible with them.

7.6.2 Standard Operating Procedures

Standard operating procedures should present, in some detail:

(a) how each task is to be carried out to meet its objective in a safe manner.

(b) the protective devices that are to be used.

(c) the signs of impending problems or dangers and
(d) the remedial, protective and emergency measures that are to be taken.

Since these procedures must relate to the specific equipment and instrumentation chosen for the project, the present report can only propose, in general terms, the approach which should be adopted. It is recommended that the project planning team should include a person assigned responsibility for Operational Safety. This person would be required to coordinate the hazard analysis by considering the various aspects of the project such as drilling, blasting, instrumentation, equipment handling, etc. and would be responsible for gathering the relevant Codes and Regulations in force. The "Standard Operating Procedures" would then be produced in collaboration with other members of the planning team. Once the project gets underway, this person would watch over the implementation of the Standard Operating Procedures making modifications as required in the light of job-site experience. This person would take care of all liaison regarding safety and health between the research project team, the management of the underground facility in which the project was sited and the Officers of Occupational Health and Safety Department.

7.6.3 Training and Supervision

The Hazard Analysis, preparation of standard operating procedures and the requirements of the project site will indicate those areas where particular experience and/or competency are needed to implement the operating procedures. This may indicate that informational and training classes are required. For example:

(a) proper use and care of lamps self rescuers, and monitoring instruments.
(b) the banning of matches and lighters underground and a no-smoking rule.
(c) fire fighting drills and emergency procedures.
(d) first aid training.

Personnel employed on the project will be a mixture of workman, engineers, scientists and technicians. The day to day operations should be supervised by people able to maintain a practical balance between the need for:

(a) carrying out underground work tasks efficiently and safely.
(b) obtaining instrumentation readings.
(c) attention to detail, vigilance and constant, careful, observation of the surroundings.
(d) care in handling and placing recording instruments in "hard-to-get-at" locations.

Much of the work will not follow routine mining practices; at times it will be unique, or at least unusual, attended by the likelihood of accident risks. The selection of supervisors will be a most important factor in achieving not only a safe project but a successful one.

SECTION 8

FOLLOW-UP RESEARCH WORK

SECTION 8

FOLLOW-UP RESEARCH WORK

8.1 INTRODUCTION

Research work as part of the experiments proposed in this report provides reliable field data on oil sands properties at as low a cost as possible and at limited risk. As outlined in Section 6.2 and 6.3 the main objectives of the proposed Phase I and Phase II experiments is to establish an in situ site from which tunneling and other research activities can be undertaken. This section briefly describes research activities that will lead to a better understanding of the in situ behaviour of intermediate and deep oil sands and will ultimately lead to the development of techniques that can be utilized for improving in situ bitumen recovery.

8.2 PERMEABILITY ENHANCEMENT

8.2.1 General

Improved bitumen recovery from oil sand is a primary objective in an in situ process. The success of the process, regardless of the methods used, is dependent on the ability to introduce sufficient permeability to allow for efficient movement of liquids and gases. Consideration is being given to techniques such as explosives or propellants, hydraulic fracturing and caving in an attempt to enhance permeability.

Testing and observation of many of these techniques can be undertaken more effectively from an in situ research tunnel than from surface or from tunnels in the underlying limestone. The tunnel facility provides a realistic environment for test work as well as allowing for in situ mining for direct observation of the results.

8.2.2 Dynamic Fracturing by Explosives

The use of high energy explosives to enhance permeability in an unconsolidated sand formation is not recommended since the ductile behaviour and the absence of tensile strength is not conducive to fracture generation. Laboratory tests by Plewes, Scott and Hsu (1984) indicated that this is not the case for oil sands which act more like a soft dense sandstone, rather than unconsolidated sands. In situ testing will provide a low cost opportunity to determine fracture development through the use of a single high strength explosives charge or the use of tailored pulse techniques or propellants. The latter technique depends on controlled pressure time behaviour to minimize well bore damage and maximize fracture growth by gas penetration.

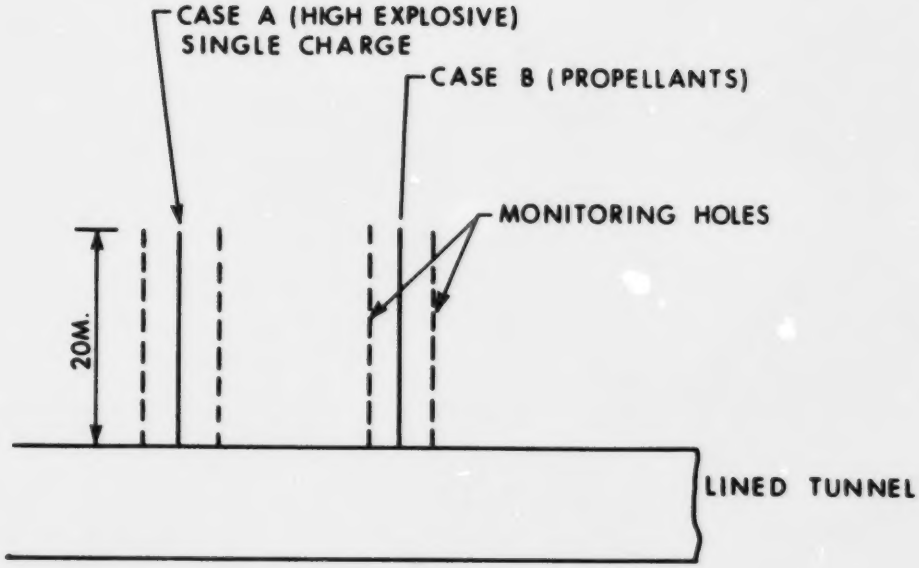
Details of the research work will be finalized after initial test work has been completed to determine material properties. Research would include the design, layout, drilling and detonation of explosives in a remote area of a research tunnel (Figure 8-1). Monitoring of pre and post detonation permeability would utilize air injection techniques. Alternately a tracer dye could be used to indicate fracture generation during a mining out process. The latter alternative of determining test results is considered more costly and would be used on a very limited basis.

Research should also be conducted on blast hole diameter optimization and the use of fracture starters to increase fracture extension as well as control fracture direction.

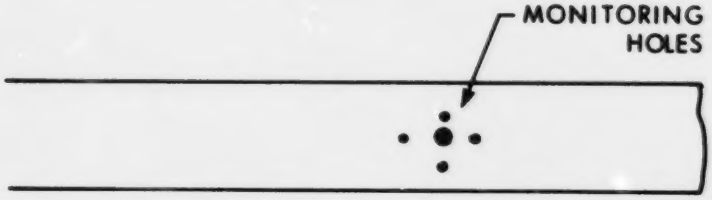
8.2.3 Hydraulic Fracturing

Hydraulic fracturing in deep oil sands has not been totally successful due primarily to the inability to generate horizontal fractures. Fractures also tend to be controlled by planes of partings or lithological differences. Dusseault (1980) states, "Predictive capabilities must be developed in these materials, and real-time monitoring of fracture growth (preferably by a

PLAN VIEW



VERTICAL SECTION



NOTE: LAYOUT MUST ULTIMATELY ALLOW FOR STEAM INJECTION TRIALS

DEPARTMENT OF SUPPLY AND SERVICES	
SCHEMATIC ILLUSTRATION OF CONTINUED RESEARCH IN OILSANDS TUNNEL	
	FIG. 8-1

surface method) should be utilized systematically in order to plan injection and production strategy in a more rational manner".

Design of hydraulic fracturing tests from an in situ site will allow detailed analysis of results at relatively low cost.

8.2.4 Caving

Caving of oil sands into a void created at the base or within the oil sands formation is expected to result in increased permeability on a localized basis. The manner in which caving will occur as well as the zone of influence are unknowns. Techniques for excavation of voids may include hydraulic jetting or tunneling.

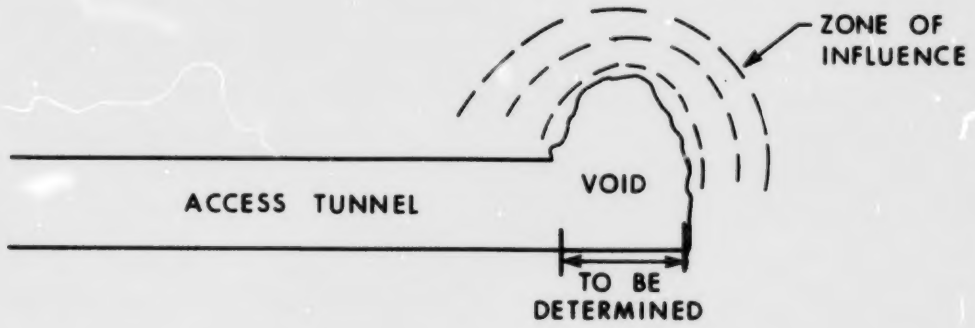
Research work from the in situ tunnel would involve the creation of a void at the end of a tunnel followed by observation of the caving mechanisms (slabbing) and the determination of the zone of influence by remote monitoring (using air injection techniques) as shown on Figure 8-2.

Based on field tests, it should be possible to determine the void pattern required for increased permeability.

8.3 STEAM INJECTION TRIALS

The magnitude of problems associated with the impact of steam injection on tunnel lining design has not been totally quantified. It may be possible through steam injection tests, on a localized basis, to determine the extent of oil sands swelling and the impact on tunnel lining. In addition, high temperature conditions which can cause difficulties for worker access and maintenance activities can be evaluated.

Permeability enhancement techniques were identified in Section 5.2. Field scale tests of the relative improvement in bitumen recovery using the standard



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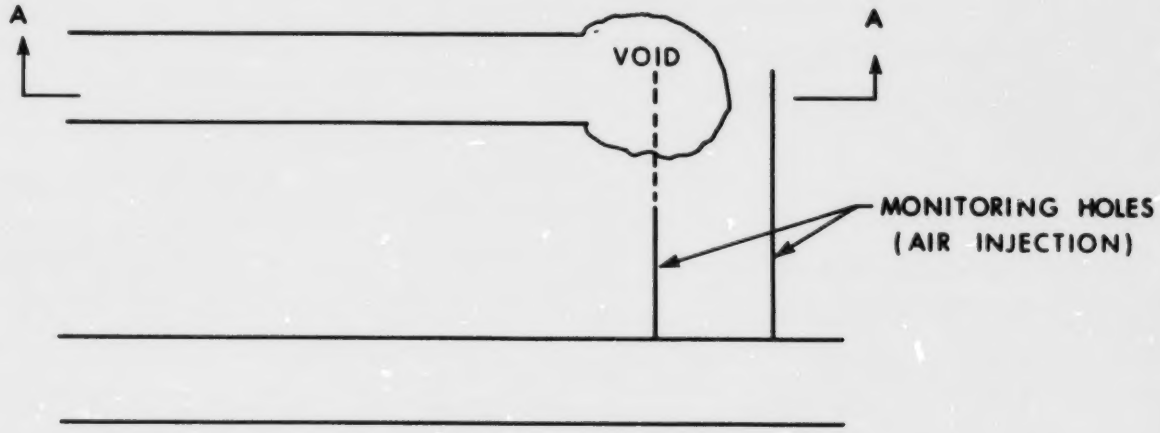

PLAN VIEW (PARALLEL TUNNELS)

DEPARTMENT OF SUPPLY AND SERVICES

SCHEMATIC ILLUSTRATION
OF CAVING EXPERIMENT IN
OILSANDS TUNNEL

		FIG. 8-2

steam injection recovery process could be undertaken following completion of permeability enhancement tests.

Research activities on steam injection directly from an oil sands tunnel could be undertaken in a section of the in situ tunnel that was initially used for permeability enhancement trials. The test area should be isolated from the shaft pillar as well as other areas of concern prior to steam injection.

The initial layout for permeability enhancement tests should reflect the requirements for steam injection as well as leaving undisturbed reference areas.

8.4 HYDRAULIC EXCAVATION

Oil sands are an extremely abrasive material which result in high wear on equipment when mechanically mined and transported. In addition, the sticky nature of bitumen causes problems in materials handling. Hydraulic excavation combined with hydraulic transport may provide an alternative to mechanical techniques.

Hydraulic mining techniques are well developed for coal recovery from underground mines (Westar Mining in British Columbia as well as Japanese and Russian Mines). Techniques include the cutting and removal of material from the working face, transporting (fluming) to a dewatering point and pumping to surface. The method generally uses high pressure high volume water for coal excavation.

Potential application to underground oil sands mining is as follows:

1) Tunneling

   Hydraulic excavation of face material utilizing low volume/high pressure jets combined with high volume transport. Difficulties can be expected in the general working conditions at the face. The affect

of hydraulic jetting on downstream processing would also have to be evaluated.

2) Caving

Remote excavation of voids to initiate caving and enhance permeability. Voids could be created at the footwall or within the oil sands formation to provide better coverage.

3) Use of high pressure water jets to drill small diameter (10 cm) holes. A patented system has been developed by Bechtel Investments Incorporated which provides a drilling rate of 3 to 30 meters per minute with holes up to 60 meters in length and up to 24 holes on any given horizontal plane. Potential exists for drilling steam injection and bitumen recovery holes using this technique.

4) Use of a horizontal jet to mine large quantities of oil sands from a vertical borehole located in the formation either from surface or from limestone tunnels under the oil sands.

An area of concern would be the stability of the cavity created by this method. The high volume of materials to be handled could also result in the method being uneconomical.

The in situ research tunnel provides an opportunity for both low cost hydraulic jetting experiments and development of borehole drilling techniques.

SECTION 9

ASSESSMENT OF OPPORTUNITIES

SECTION 9

ASSESSMENT OF OPPORTUNITIES

9.1 CHALLENGE

A significant challenge is presented to the Canadian mining and oil industries by the oil sands of Alberta. That challenge is to maximize economical extraction of oil from the vast reserves of northern Alberta.

In the oil sands, in situ projects are meeting with limited success, due to a number of factors including permeability variations and communication problems within the reservoir, geology, reservoir geometry, etc. The Canadian oil industry is, however, demonstrating admirable persistance. In April, 1985, there were 57 experimental oil sands, heavy oil and enhanced oil recovery pilot projects operating in Alberta under ERCB approval. The number of active projects, given the very limited success achieved, attests to the enormous potential of the oil sands. How can the underground mining community contribute to this technological explosion?

No one can deny the break throughs that have been made in surface mining of oil sands. That industry, too, has geological and economic limitations, and the huge pits will eventually be reclaimed and abandoned. Oil reserves will be left in place adjacent to the abandoned mines, too deep for surface mining, too shallow for "conventional" in situ extraction techniques. Can underground mining expertise play a role in economical recovery of these oil reserves?

9.2 OPPORTUNITIES AND CONTRIBUTIONS

A number of opportunities confront the mining industry. They include:

(1) Participation in future oil sands development cannot be ignored. When oil recovery schemes using underground access are developed they will

require underground mining expertise for concept development, design, construction, management and extraction activities. Opportunities will exist for mine operators, construction or mining contractors, and engineering and consulting firms.

(2) There have been no major underground excavations in oil sand. Expertise in working in this unique environment must be developed through experience. Experience gained here will almost certainly have applications in other mining sectors.

(3) The particularly abrasive and sticky environment encountered in mining oil sands on any scale will encourage the development of new or improved equipment to address cutting and handling problems.

(4) The potential for the application of thermal in situ processes from tunnels will encourage the development of new underground drilling techniques and equipment, specialized shielding and supporting techniques, remote mining techniques and equipment, and specialized health and safety practices including remote environmental monitoring systems and self rescue equipment.

As experience is gained in dealing with oil sands and the associated unique problems, contributions will be made to the resource industry which may have broad applications. These contributions might include:

(1) Provision of basic data on in situ material properties of oil sand.

(2) Improved recovery, in terms of both volume and rate, of oil from in situ process schemes.

(3) Techniques, developed either independently or in conjunction with in situ process specialists, for the exploitation of oil sand reserves adjacent to surface mines.

(4) Techniques enabling additional production from reservoirs from which it is difficult to obtain production using standard oil industry practices. Such reservoirs might include those with very low permeability or complex stratigraphy such as discontinous or interbedded strata.

(5) Techniques developed might find applications in the exploitation of other resource commodities. An example might be bulk caving or rubblizing of large low grade mineral deposits with injection of fluids for subsequent leaching and recovery of metals. Indeed, the oil industry might make contributions to the mining community.

A generation ago, buildings were used to house the computing capability now available in hand held calculators. No one will deny that those first few computing steps were simple and basic, but equally, no one will deny that they formed the foundation for today's computer technology. So too, the mining industry must take its first few simple and basic steps to form the foundation for future participation in oil sands exploitation.

AOSTRA has shown foresight and courage in taking steps to construct the Underground Test Facility. The oil industry is expressing its support, and has been stimulated to develop in situ process technology that can be used at the UTF to economically extract greater volumes of oil from the sands. The mining industry would be remiss if it did not also contribute its knowledge and expertise to the search for improved oil recovery.

SECTION 10

CONCLUSIONS AND RECOMMENDATIONS

SECTION 10

CONCLUSIONS AND RECOMMENDATIONS

10.1 CENTRES OF EXCELLENCE

While it is difficult to identify centres of excellence committed to the study of petroleum mining methods, it is appropriate to comment on regions where petroleum mining methods are being promoted.

(1) AOSTRA has demonstrated its confidence in the application of underground mining methods to enable improved oil recovery by in situ process techniques. While oil mining, or the application of mining methods for purposes other than access, is not actively promoted by AOSTRA neither has it been rejected.

(2) In terms of commitment to oil mining, Romania is probably the world leader. Oil mining activities were initiated in 1925, and continued intermittently to the present. In recent years, oil mining has been pursued more intensively and this enhanced oil recovery method currently has a position of prominence in that country's energy development philosophy. Unfortunately, there are very few references to Romanian activities in publicly available literature.

(3) The Soviet Union is persisting with commercial development using tunnels for access for gravity drainage in situ process schemes, and has more than a decade of research and experience behind them. Again, unfortunately, there are few references to these activities in publicly available literature.

(4) Oil mining and mining assisted in situ process activities in the United States have been mainly within the private sector, and for that reason

results of research and trial mining schemes are considered proprietary. Relevant research and development activity is likely to remain in the private sector in the U.S. for some time. Projected Department of Energy funding for enhanced oil recovery research for fiscal 1986 is only $12 million, including $1.4 million for oil sands. Although oil mining advances may be made in the private sector, it will be difficult to access specific or detailed information on the developments.

10.2 CONCLUSIONS

(1) Information to be gained from the proposed experiments will move underground oil sand mining studies out of the realm of speculation, and into the domain of applied research. Hard data will be available on which mining assumptions and parameters can be based.

(2) While more elaborate experiments were considered during the early stages of this study, they would provide no more hard data on in situ oil sands behavior than those proposed, which offer the least risk, most readily managed, lowest cost way to obtain the data.

(3) It is not possible to predict how the oil sand will behave during the experiments. The "hands on" experience gained will guide both ongoing and future research.

(4) As a general principle, it must be accepted that in common with all underground mining operations, the ground itself will dictate how it will be mined. The challenge is to develop mining methods and extraction procedures without precedent. This cannot be done without hard data on which to base assumptions and design criteria. The material behavior requires that research be done in the field, and not just on paper or in a laboratory.

(5) The value of the experiments is:

- Direct experience and systematic measurement of the behavior of oil sand when excavated on a large scale is obtained.

- Reliable parameters can be established enabling the feasibility of underground mining to be assessed technically and economically before funds are committed to an actual mining project.

- Small scale extraction and rubblizing is conducted in a manner which is safe and in which persons are not required to work in locations where unmanageable hazards may exist.

- The small scale operation allows a careful health hazard analysis to be conducted and samples taken of water, bitumen and gases.

- If the capability of increasing the permeability of the oil sands is demonstrated from tunnels located in the competent limestone below, then direct mining within the oil sands themselves may not be necessary in order to enhance recovery of bitumen.

10.3 RECOMMENDATIONS

Many recommendations for future research depend quite heavily on the observations and results of the proposed experiments. There is, however, some research which can be conducted independently, as outlined below:

1) This study has identified a number of patents which may have a bearing on future applications of underground mining techniques in Alberta's oil sands. It has not, however, included an indepth analysis

of the technical application of these patents in an underground mining environment in oil sands.

2) Syncrude is currently involved in an evaluation of the application of hydraulic extraction techniques beyond a highwall at the mine. CANMET may be able to support or complement Syncrude research.

3) Two specific surveys should be completed in the near term. Both will have direct applications in any underground oil sands mining activity, and will likely have applications in current and proposed surface oil sands mining ventures. Neither is dependent on the results of the proposed experiments.

   a) The particularly sticky nature of oil sands will require special liners for skips, chutes, conveyors, LHD's and other contact areas in any materials handling system. An investigation of the availability, cost and ease of use of appropriate liners is required for future activities.

   b) Abrasion resistant extraction and materials handling equipment will be required for any underground oil mining activity. A survey of the art covering abrasion and wear resistant mining and conveying equipment will be invaluable in assessing underground mining applications in oil sand.

4) Prior to a commitment of funds to completion of Phases 1 and 2, significant progress could be made by initiating part of the Preliminary Work for Phase 1. This could include regulatory approvals, detailed design of Phase 1 and discussions with AOSTRA.

APPENDIX A

GEOLOGICAL, GEOTECHNICAL AND HYDROGEOLOGICAL SITE DATA

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- Specialized Field Testing
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APPENDIX A

GEOLOGICAL, GEOTECHNICAL AND HYDROGEOLOGICAL SITE DATA

A-1 GEOLOGY

Stratigraphy

Overburden materials consist of Pleistocene sediments, Grand Rapids Formation, Clearwater Formation, and that portion of the McMurray Formation above the main oil sand zone. The main oil sand zone generally lies unconformably on Devonian limestone, and in places a very thin bed of clay or sand separates the oil sand from the Devonian limestone. Formations and average thicknesses are shown in Table 1, and described below. The results of a second exploration program completed in 1984 are not incorporated in this report. The second exploration program did not identify any significant changes in structure or stratigraphy.

Pleistocene glacial sediments consist of one to two metres of glaciolacustrine silts and clays which overlie till deposits of clays, silts, sands, and boulders. In the drilled area Pleistocene sediments average about three metres in thickness.

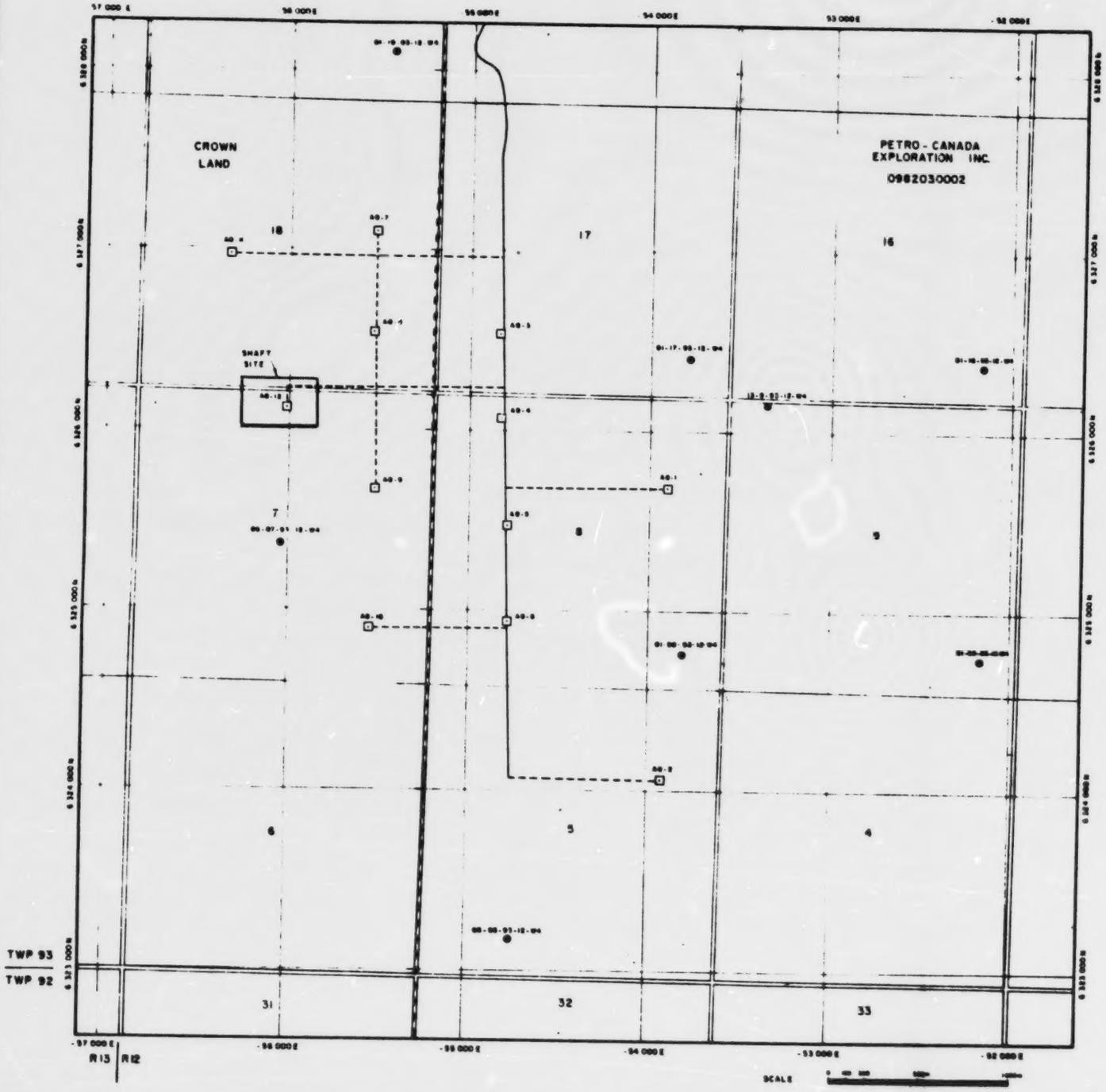
The Grand Rapids Formation ranges from predominantly fine grained sand through varying percentages of sand, silt, and clay. In the northern part of the explored area (Figure 1) the Grand Rapids sediments are similar to underlying Clearwater strata.

The Clearwater Formation has been subdivided informally into eight units, the Wabiscaw (Kcw), and units Kca through Kcg. These units consist of a regionally extensive marine sequence of clays, silts, and fine grained sands intercalated with indurated siltstones, and locally, smectite-rich mudstone beds. The Wabiscaw, at the base of the Clearwater Formation is

TABLE 1

STRATIGRAPHY IN VICINITY OF UNDERGROUND TEST FACILITY
(from Surface to Waterways Christina Member)

Age	Formation	Member	(Thickness) at Site	Material
Quaternary	Pleistocene - Recent	-	3 - 5 m	Till, glaciolacustrine and glaciofluvial sediments, organics
		EROSIONAL UNCONFORMITY		
Upper Cretaceous	Grand Rapids	-	54.2 m	Interbedded, poorly indurated, claystone, siltstone and glauconitic sandstone, with significant silty and clayey sand zones.
Lower Cretaceous	Clearwater Formation	kcg	-	Predominantly claystone, minor siltstone and sandstone.
		kcf	18.5 m	Sand and silt, with claystone and siltstone lenses. Three sandstone lenses.
		kce	5.1 m	Predominantly claystone and siltstone, minor silt and sandstone.
		kcd	13.6 m	Claystone at top of unit; remainder predominantly sands, sandstone and siltstone.
		Kcc	22.1 m	Thick claystone unit, with siltstone lenses.
		Kcb	5.5 m	Predominantly claystone at top and sand at bottom.
		Kca	3.7 m	Predominantly claystone.
		Kcw (Wabiskaw)	0.6 m	Thin glauconitic sandstone.
	McMurray Formation	Marine	9 m	Fine- to medium-grained, glauconitic, gas-bearing sand overlying muddy and silty, fine- to very fine-grained sands and silty muds.
		Estuarine	29 m	Oil impregnated, fine-to medium-grained quartz sands, occasional siltstone and claystone layer.
		EROSIONAL UNCONFORMITY		
Upper Devonian	Waterways Formation	Moberly	28.5 m	Thin bedded, argillaceous limestone and massive limestone.
		Christina	22 (+) m	Calcareous shale and argillaceous limestone.



AOSTRA UTF PROGRAM

LEGEND

ACCESS ROADS
- PRE - 1983 ——
- 1983 DRILLING ——

SHAFT SITE

DRILL HOLES
- PRE - 1983 ●
- 1983 DRILLING ⊔

- - - - - - BOUNDARY BETWEEN CROWN AND PETRO-CANADA LANDS

DEPARTMENT OF SUPPLY AND SERVICES

UNDERGROUND TEST FACILITY

EXPLORATION DRILLHOLE LOCATION MAP

DATE: JUNE, 1985

SOURCE:

FIGURE: 1

predominantly a glauconitic sandstone. Units Kcb, Kcd, and Kcf are predominantly silts and very fine sands with lesser clays. Units Kca, Kcc, Kce, and Kcg are dominantly claystone. In the southern part of the explored area unit Kcg and, locally, Kcf and Kce are absent due to the presence of a thick sequence of Quaternary sands.

The McMurray Formation is composed of fluvial/marsh, estuarine, and marine sediments. The uppermost strata are marine sediments consisting of beach and foreshore sands. The sands are generally fine- to medium- grained, with local coarse- to very coarse- grained units. These sediments are potentially gas-bearing, although pressures are expected to be low, since no problems were encountered during drilling. These sands overlie a sequence of marine, muddy and silty, fine- to very fine- grained sands and silty muds.

The major occurrence of bitumen is in sediments representing upper and lower estuarine channel environments. Upper estuarine channel sediments consist of thick sequences of fine- to medium- grained quartzose sands. Occasional clay laminae are found in millimetre to centimetre size drapes marking boundaries between beds or channel sands. Bitumen content is relatively high. Lower estuarine channels consist of fine- to very fine-grained silty sands with centimetre size clay interbeds. Bitumen content in lower estuarine sediments is confined to the sandy units. In some places channel breccias occur within the estuarine strata. Centimetre size clasts of clay and silt occur in a bituminous sandy matrix. Tidal flat sediments, consisting of silty and sandy mudstone, and silty sands interfinger with, and in some places overlie, the estuarine channel sands. Locally, the sandier tidal flat units contain minor bitumen quantities.

The lowermost McMurray unit consists of fluvial/marsh sediments. These sediments, dominantly sand and sandy muds, directly overlie the Devonian, and include root casts and coal fragments. The muds and sands are often referred to as basal clays and basal sands, respectively.

Only the top portion of the Waterways Formation (Moberly, and possibly Christina members) was penetrated during the geological drilling programs. A variety of limestone lithologies have been identified in Devonian core, including thin bedded, argillaceous and micritic limestones, thin biogenic limestones, and a relatively thick (approximately 10 metres) and massive, biohermal limestone. These units are laterally continuous and can be correlated between drillholes. Beneath this sequence of limestone is a widespread unit, of unknown thickness, consisting of calcareous, laminated mudstones and shaly limestone.

Structure

In the general location of the UTF shaft site the Devonian surface ranges in elevation from 254 to 272 metres AMSL and can be considered to maintain

a gentle slope to the west with a gradient of approximately 5 metres/kilometre. However, because the contact between the McMurray and Waterways Formations represents an erosional surface there are local variations in the direction and magnitude of the gradient.

The limestone bedding is generally massive and flat with dips rarely exceeding 2^{o}. Occasional tight, vertical joints were identified in the limestone core.

The McMurray Formation as illustrated in Figures 2, 3 and 4 generally follows the trend of the underlying Devonian surface. Internal sedimentary structural characteristics occuring within the estuarine environment sediments consist of occasional cross-beds, ripple marks, burrows, flaser bedding, lenticular bedding and wavy-parallel-laminar bedding.

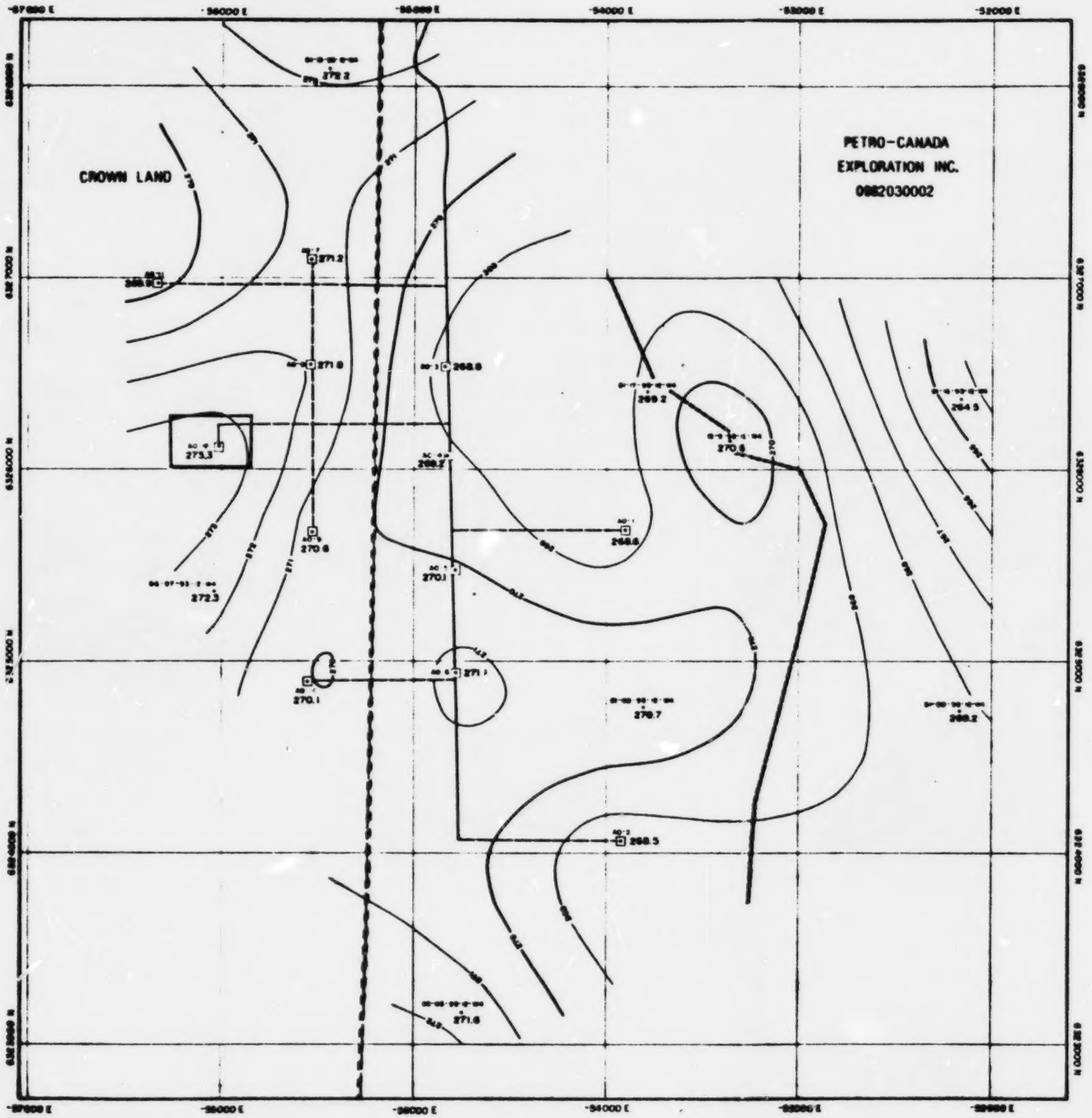
Localized shear planes created as a result of slump structures are common in these units, however, rehealing of the fractures has occured.

The McMurray marine unit is characterized by strong bioturbation giving internal clay bands a "branching structure".

The Clearwater Formation generally follows the structure of the Devonian surface with internal sedimentary structures consisting of parallel, even bedding. Dips are generally flat but occasionally reach 5^{o}. Jointing is relatively common with dips ranging from nearly flat to 90^{o}. These joint planes are sharp and continuous in core.

The distribution of the Grand Rapids Formation is controlled by the Quanternary erosional surface which generally slopes toward the east.

Data by Babcock, (1975 reference) suggests that the Waterways Formation is interrupted by two orthogonal regional joint systems; one set is oriented north and east; the second is oriented northwest and northeast. In contrast,



AOSTRA UTF PROGRAM

LEGEND

ACCESS ROADS
- PRE-1983
- 1983 DRILLING

DRILL HOLES
- PRE-1983
- 1983 DRILLING

SHAFT SITE

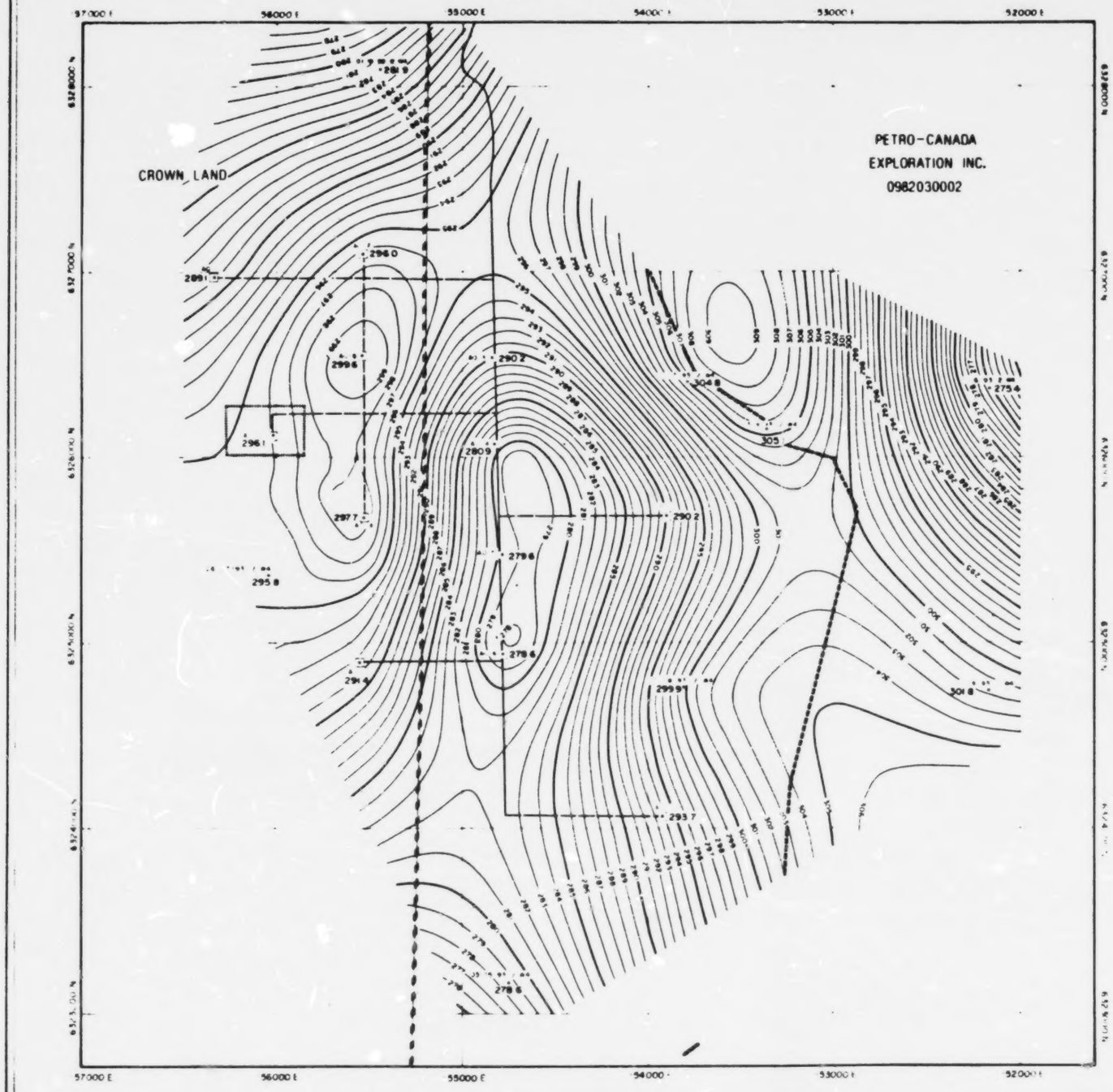
BOUNDARY — Separates Crown Land and Petro-Canada Lease

NOTE:
ELEVATIONS IN METRES
—— APPROXIMATE 91.4 m OVERBURDEN LIMIT

SCALE

DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY
BASE OF ORE BODY
STRUCTURE CONTOUR MAP

DATE: JUNE, 1985
SOURCE: E.R.C.B. Application
FIGURE 2



AOSTRA UTF PROGRAM

LEGEND

ACCESS ROADS
- PRE 1983 ——
- 1983 DRILLING ——

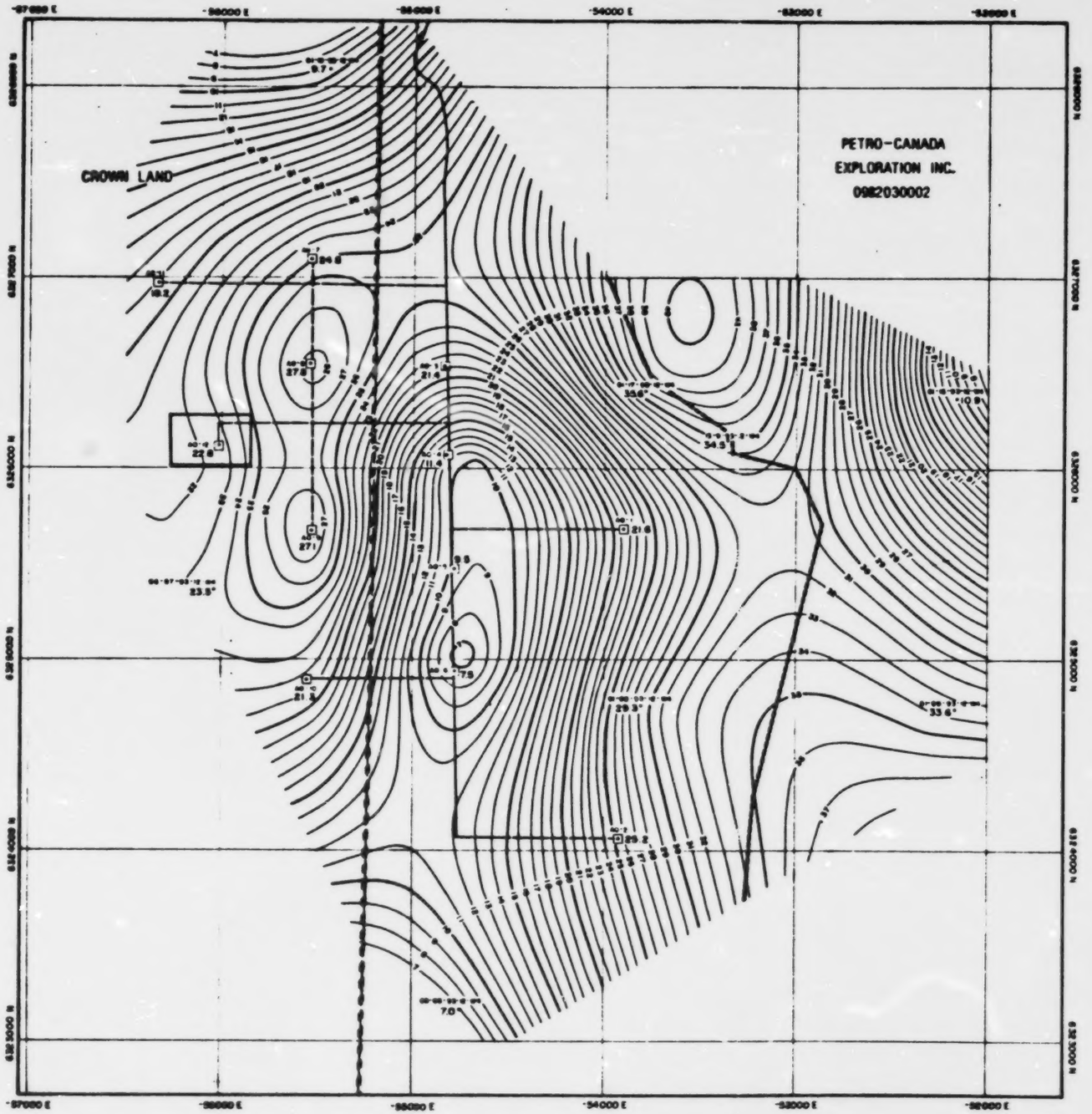
DRILL HOLES
- PRE 1983 ·
- 1983 DRILLING ·

SHAFT SITE

BOUNDARY — — — — Separates Crown Land and Petro Canada Lease

NOTE:
ELEVATIONS IN METRES
—— APPROXIMATE 91.4m OVERBURDEN LIMIT

DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY TOP OF ORE BODY STRUCTURE CONTOUR MAP
DATE JUNE, 1985
SOURCE E.R.C.B. Application
FIGURE 3



AOSTRA UTF PROGRAM

LEGEND

ACCESS ROADS
- PRE - 1983
- 1983 DRILLING

DRILL HOLES
- PRE - 1983
- 1983 DRILLING

SHAFT SITE

BOUNDARY — Separates Crown Land and Petro-Canada Lease

NOTE:
THICKNESSES IN METRES
APPROXIMATE 91.4m OVERBURDEN LIMIT

SCALE

DEPARTMENT OF SUPPLY AND SERVICES

UNDERGROUND TEST FACILITY

MAIN ORE BODY
ISOPACH MAP

DATE JUNE - 1985

SOURCE E.R.C.B. Application

FIGURE 4

the McMurray Formation exhibits only the northeast and northwest orthogonal set. Because joints are typically near vertical and wide spaced intersection of frequent jointing in vertical boreholes is not expected.

Reserves

Ore has been defined for our purposes as contiguous sands containing ten (10) percent or more bitumen by bulk weight. Zones having less than six (6) percent bulk weight bitumen and thicker than 1.5 metres were considered as reject. Average Ore Grade Data is given in Table 2.

Only the main ore body was considered in the calculation of in situ bitumen reserves. Other bitumen-bearing zones, which meet ore zone criteria, have not been considered when separated from the main ore body by more than 1.5 metres of non-ore material. It is probable that the in situ recovery techniques applied will recover additional bitumen from the lower grade sands although such bitumen has not been considered in the reserves as stated in this report.

Strict geographic limits were imposed on the ore body. These limits are shown on the In Situ Bitumen Isopach Map, Figure 5. Lack of reliable data prevented confident extrapolation of trends beyond these limits. The minimum acceptable overburden thickness was 91.4 m (300 foot cut-off limit), overburden depths increased to over 148 metres towards the western boundary of the reserve area. For the purpose of this study only that portion of the ore body located below Crown land and west of the Petro Canada Leases is considered.

Regionally the base of the main ore body, Figure 2, is approximately parallel to the structure top of the Devonian Limestone. Minor areas of basal clay and water-bearing sands exist.

TABLE 2

ORE GRADE DATA

	Total McMurray Fm.		Main Ore Zone	
	Thickness[1]	Overall Grade[2]	Thickness[1]	Grade[3]
Hole No.	(m)	Bulk Weight %	(m)	Bulk Weight %
AO-01	40.40	11.05	21.30	14.62
AO-02	37.70	9.74	25.20	13.42
AO-03	36.40	8.17	19.40	13.09
AO-04	36.90	7.78	11.70	14.75
AO-05	35.60	7.20	9.50	15.29
AO-06	32.30	7.19	7.50	15.59
AO-07	37.30	9.62	24.50	11.76
AO-08	36.20	11.28	27.10	13.68
AO-09	36.90	10.56	25.60	14.23
AO-10	36.00	8.69	20.60	13.59
AO-11	35.00	8.70	19.20	11.80
AO-12	36.50	10.24	22.20	13.79

Notes:

1. Excludes missing core.
2. Determined from the sum of thickness X grade for all samples divided by total thickness (excluding missing core intervals) as per oil-water-solids laboratory analyses.
3. Determined from contiguous oil-bearing sediments with ten or more bulk weight percent oil containing no reject zones thicker than 1.5 m with less than six percent bulk weight oil.

The top of the ore body is shown on Figure 3 and an isopach of the thickness of the ore body is shown in Figure 4.

Two dominant stacked channel sand sequences have been identified in the McMurray Formation. Both have a northerly trend as shown by the main ore zone isopach (Figure 4). The western channel sand sequence is located primarily on Crown Land, and the eastern channel sequence is located on Petro Canada Exploration Inc. Oil Sands Lease No. 09 82 030002.

Table 3 summarizes the volume and percentages of in situ bitumen on Crown Land and on the Petro Canada Lease. Total amount of bitumen in situ in the main ore zone is estimated at 52.0 x 10^6 tonnes or 51.7 x 10^6 m^3 (325.3 x 10^6 barrels). Approximately 35 percent is present on Crown Land and 65 percent present on the Petro Canada Lease (Figure 5). The ore body area considered as probable reserve is 879.98 hectares, or 3.4 square miles.

Bitumen Distribution as a Function of Facies

Borehole data throughout the Athabasca area and at the UTF site demonstrate that the lithology and hence the reservoir characteristics vary distinctly from hole to hole. Both porosity and oil saturation are controlled by facies distribution, with the cleaner and coarser estuarine channel sands having higher oil saturations. Facies changes can be rapid and extreme resulting in difficulties in preparing reliable detailed McMurray correlations, in other than a general sense, throughout most of the Athabasca area.

Lean bituminous zones and reject zones containing less than 6% oil by weight do occur within the estuarine channel sands and generally consist of finely interbedded silty clays, silty sandy clays and frequent nodules of sideritic "ironstone". Individual tidal flat units are difficult to correlate from one drillhole to another, and are considered to be of local areal extent. They could possibly provide a barrier to fluid flow. The geometry of the tidal flat interbeds is affected by scouring in places, thereby allowing the original

TABLE 3

BITUMEN IN SITU WITHIN ORE BODY LIMITS

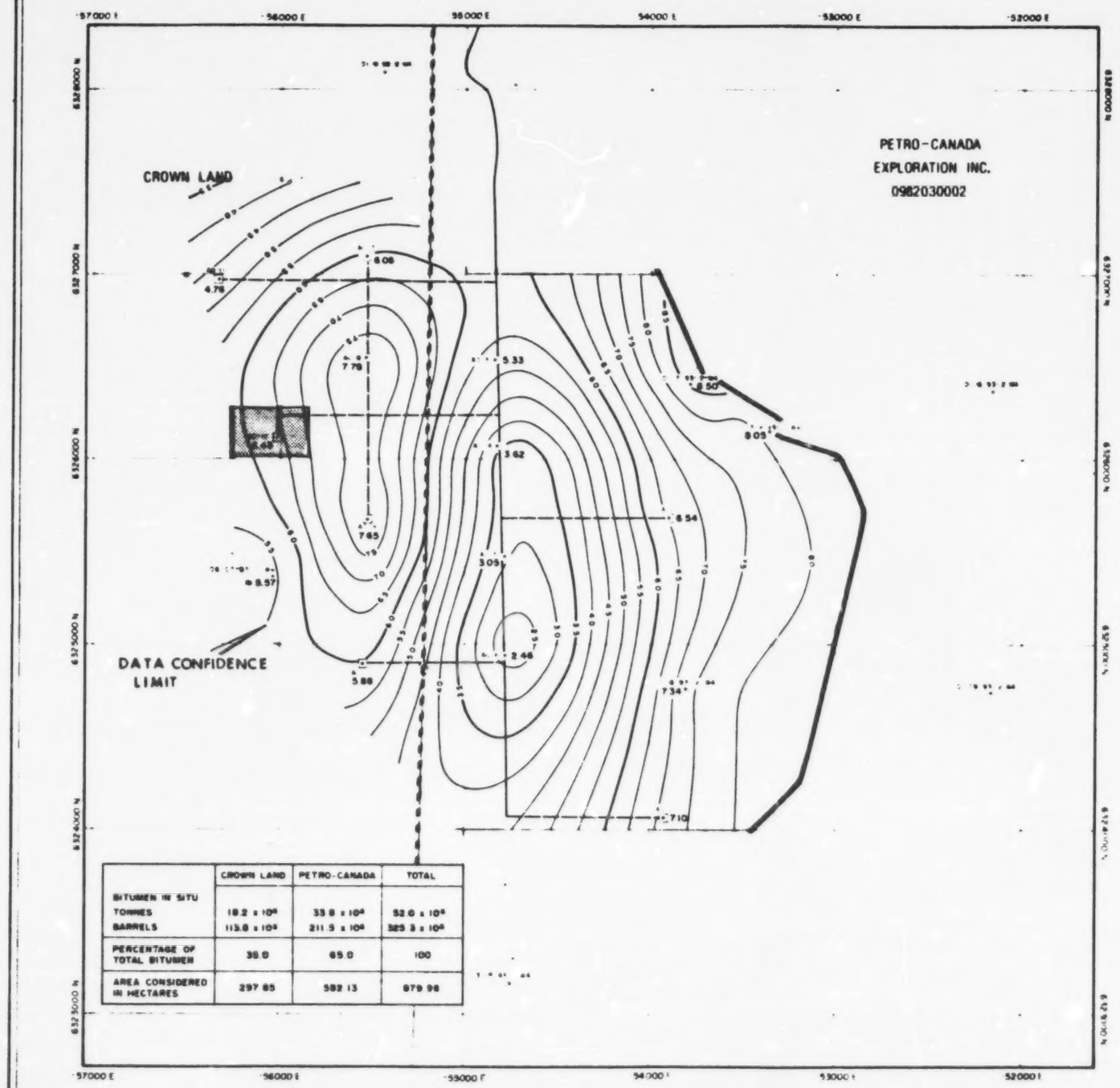
	Crown Land	Petro Canada	Total
Bitumen in situ			
Tonnes	18.2×10^6	33.8×10^6	52.0×10^6
Cubic Metres	18.1×10^6	33.6×10^6	51.7×10^6
Barrels	113.8×10^6	211.5×10^6	325.3×10^6
Percentage of total bitumen	35	65	100
Area considered in hectares	297.85	582.13	879.98

Assumptions:

(1) Bulk density of oil sands is 2.1 g/cm^3.

(2) One barrel equals 160 litres.

AOSTRA UTF PROGRAM



	CROWN LAND	PETRO-CANADA	TOTAL
BITUMEN IN SITU			
TONNES	18.2 x 10^6	33.8 x 10^6	52.0 x 10^6
BARRELS	113.8 x 10^6	211.5 x 10^6	325.3 x 10^6
PERCENTAGE OF TOTAL BITUMEN	35.0	65.0	100
AREA CONSIDERED IN HECTARES	297.85	582.13	879.98

MAIN ORE ZONE

HOLE NUMBER	THICKNESS[1] (metres)	GRADE[2] BULK WEIGHT %	METRIC TONNES[3] OF BITUMEN	BARRELS[4] OF BITUMEN
AO-01	21.3	14.62	6.54	40.87
AO-02	25.2	13.42	7.10	44.38
AO-03	19.4	13.09	5.33	33.33
AO-04	11.7	14.75	3.62	22.65
AO-05	9.8	15.29	3.06	19.05
AO-06	7.5	13.39	2.46	15.35
AO-07	24.2	11.76	6.05	37.82
AO-08	27.1	13.68	7.78	48.66
AO-09	25.6	14.23	7.65	47.81
AO-10	20.8	13.59	5.88	36.74
AO-11	19.2	11.80	4.78	29.74
AO-12	22.2	13.79	6.43	40.18
36-07-93-12W4	~23.47	~11.29	~5.57	~34.78
01-08-93-12W4	22.86	15.30	7.34	45.91
13-09-93-12W4	30.32	12.65	8.05	50.34
31-17-93-12W4	29.41	13.76	8.50	53.11

NOTES

1 EXCLUDES MISSING CORE

2 DETERMINED FROM CONTIGUOUS OIL-BEARING SEDIMENTS WITH TEN OR MORE BULK WEIGHT PER CENT OIL CONTAINING NO REJECT ZONES THICKER THAN 1.5m WITH LESS THAN SIX PER CENT BULK WEIGHT OIL

3 *ASSUME A BULK DENSITY OF OIL SANDS AT 2.1 gm/cc

*METRIC TONNES OF BITUMEN = $\frac{\text{THICKNESS(m)} \times 1\text{m}^2 \times 2.1 \times \text{GRADE BULK WEIGHT \%}}{100}$

4 *BARRELS OF BITUMEN = TONNES OF BITUMEN ÷ 0.16

*ASSUME 160 litres = 1 barrel

SCALE

BOUNDARY BETWEEN CROWN AND PETRO-CANADA LANDS

MINIMUM OVERBURDEN CUTOFF 91.4 m

SHAFT SITE

DEPARTMENT OF SUPPLY AND SERVICES

UNDERGROUND TEST FACILITY
IN SITU BITUMEN
IN
METRIC TONNES

DATE: JUNE, 1985

SOURCE: E.R.C.B. Application

FIGURE: - 5

oil saturation to occur. These tidal flat beds will tend to have higher permeability if they have undergone intense burrowing or some other sedimentary disturbance.

The distribution of fines is also facies related with the least amount of fines contained in the estuarine channel sand facies and the highest fines content occurring in the marine shore face. The lowest fines content, within the estuary channel sand facies or main ore zone, is approximately 7% of less than -325 mesh.

Core observations indicate that fracturing in the oil sands occurs as localized shear surfaces which are rehealed and rare, near vertical joints. As expected, the higher permeability values correspond with the cleaner, coarser sands while the low values occur in the visible clay layers. Barren zones of high permeablility could be encountered in the marine beach and shoreface facies. When water saturated, these may act as thief zones for injected gas or fluids if they are able to penetrate through the marine shales which overlie the ore zone.

A-2 GEOTECHNICAL

Field Investigations

A total of 20 holes were drilled during the 1983 winter drilling program. Eight of these holes were drilled (Figure 6), at or near the selected shaft site to assess geotechnical conditions. Table 4 summarizes the geotechnical drilling program. Following completion of the drilling program, the geological and geotechnical core was described and sampled for further testing.

Specialized Field Testing

Four specialized field tests were conducted at the UTF site:

Pressumeter tests in the Grand Rapids and Clearwater Formation to measure total horizontal stresses and to estimate the elastic deformation modulus of the soil and weak rock.

Packer tests at various depths in the Grand Rapids, Clearwater and McMurray Formations to measure formation water pressure and hydraulic conductivity.

Gas exhalation tests in one hole in the McMurray Formation to measure the quantity of dissolved gas expected to come out of solution when pressure is relieved.

Selected oil sand core samples were placed into sealed containers immediately after the core was brought to surface, to measure the quantities of gas escaping from the core once in situ pressure is relieved.

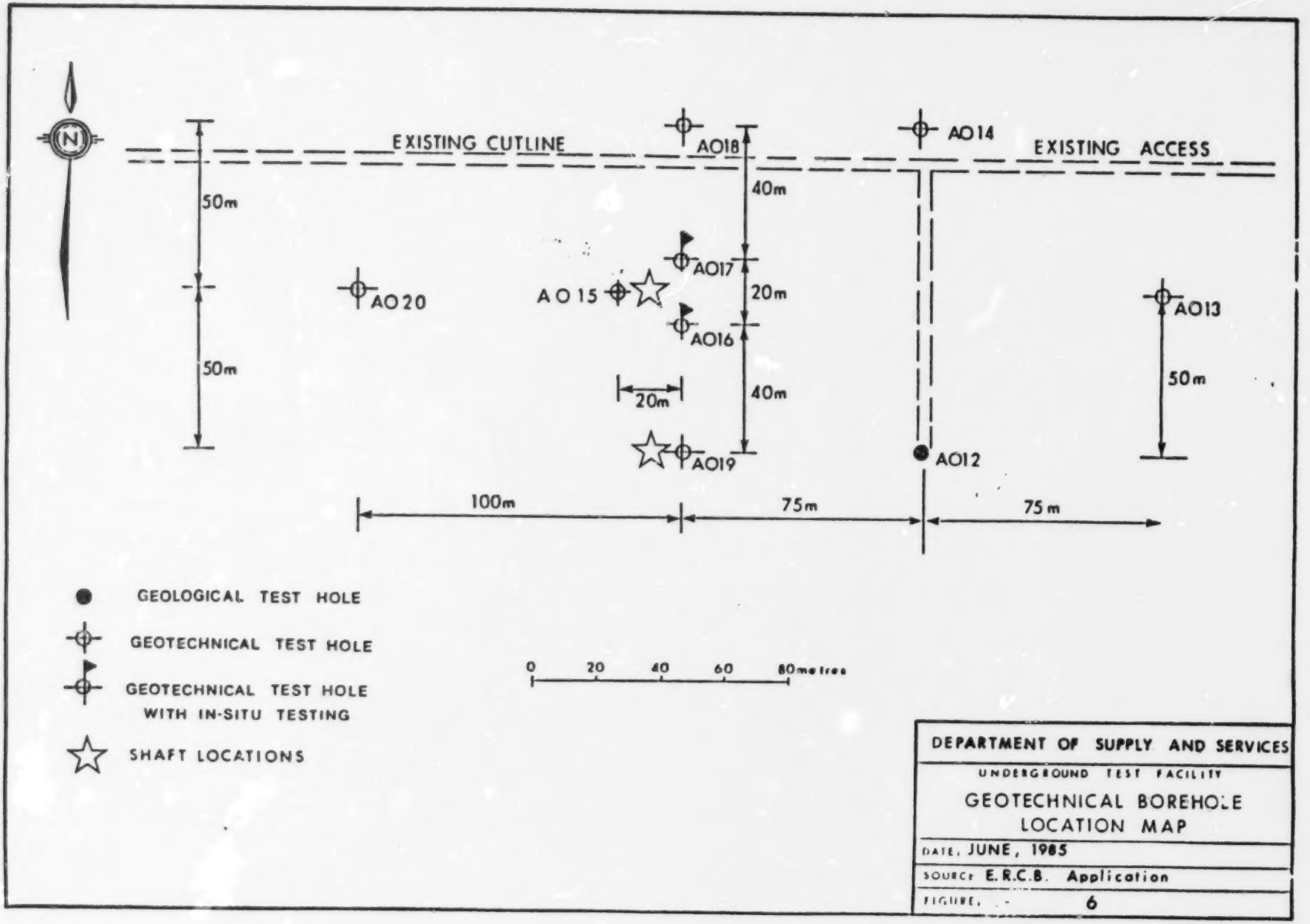

N
EXISTING CUTLINE
EXISTING ACCESS
AO18
AO14
AO17
AO20
AO15
AO16
AO13
AO12
AO19
50m
50m
40m
20m
20m
40m
50m
100m
75m
75m
GEOLOGICAL TEST HOLE
GEOTECHNICAL TEST HOLE
GEOTECHNICAL TEST HOLE WITH IN-SITU TESTING
SHAFT LOCATIONS
0 20 40 60 80 metres
DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY
GEOTECHNICAL BOREHOLE LOCATION MAP
DATE, JUNE, 1985
SOURCE E.R.C.B. Application
FIGURE, 6

TABLE 4

GEOTECHNICAL DRILLING PROGRAM SUMMARY

Borehole No.	Total Depth	Drilling Method & Hole Size	Geophysical Logs	Installations	Sampling and Testing
AO13	212.0 m (695 ft)	Cored HQ (10.11 cm), then reamed to 15.24 cm	Caliper, Gamma, Bulk Density, CNL Density, Dual Induction, Dipmeter, Sonic, Single Point Resistivity, Temperature, Stickplot, Direction Log	Standpipe (19 mm) piezometers: 200 - 207.5 (Dw) 160 - 164 m (Km) 80 - 90 m (Kc) 62 - 67 m (Kc)	Secured continuous core for laboratory testing. GW monitoring and sampling. Gas release measurements on core specimens.
AO14	205.3 m (673 ft)	Triconed HQ (10.11 cm). Cored (HQ) Dev limestone	As above	Standpipe (19 mm) piezometers. 177 - 183 m (Dw) 123 - 126 m (Kcw)	Sampling and monitoring of groundwater. Core secured from Devonian limestone.
AO15	220 m (721.3 ft)	Coring HQ (10.11 cm) then reamed to 12.07 cm	As above	Standpipe (19 mm) piezometers 200 - 210 m (Dw) 120.8 - 135.7 m (Km)	Secured continuous core. Formation pressure and permeability measured (profiler) at depths: 38.1 - 40 m/55 - 60 m, 85 - 92 m/118 - 121 m, 125 - 128.5 m/130 - 136 m, 142 - 151 m. Profiler readout unit failure precluded testing below 151 m. Gas release measurements on core specimens.
AO16	145 m (475 ft)	Triconed HQ (10.11 cm) and cored HQ within test intervals, Revert mud used for final hole interval from (140 m depth).	Caliper, Gamma, Bulk Density	Gas well point installed at 140 - 145 m (Km) following the completion of pressuremeter testing.	Determination of elastic parameters (pressuremeter tests) at following depths: 34.1, 41.2, 58.0, 71.0, 76.3 85.4, 94.6, 105, and 106.75 m. Core secured from test sections. Determination of gas exhalations (in situ).

TABLE 4 (Continued)

GEOTECHNICAL DRILLING PROGRAM SUMMARY

Borehole No.	Total Depth	Drilling Method & Hole Size	Geophysical Logs	Installations	Sampling and Testing
AO17	130 m (4263 ft)	Triconed HQ (10.11 cm) Revert mud for final hole interval (from 125 m depth).	As above	Gas well point installed at 125 - 130 m (Kcw)	Standard penetration testing and shelby tubes to 30.5 m depth. Determination of gas exhalations (in situ).
AO18	55 m (180.3 ft)	Triconed HQ (10.11 cm)	As above	Pneumatic piez. at 50 m depth (Kgr) Standpipe piez. in Quarternary overburden.	Standard penetration tests and shelby tubes undertaken to 30.5 m depth.
AO19	110 m (360.6 ft)	Triconed HQ (10.11 cm)	As above	Pneumatic piezometers at depths of 88-101 m and 56.5-64 cm (Kc) Standpipe piez. at 8-12 m (Kgr)	Standard penetration tests and shelby tubes secured to 7 m depth.
AO20	50 m (164 ft)	Triconed HQ (10.11 cm)	As above	Pneumatic piezometer 45-50 m (Kg), standpipe piez-ometers at 22 m (Kgr) and 6 m (Q) depths.	Standard penetration tests and shelby tubes secured to 24.4 m depth.

Not all of the objectives set out for specialized testing were achieved. Table 5 provides a summary of the more important results.

Laboratory Testing

Core from the geotechnical drilling program was kept unfrozen to prevent frost damage of sensitive structures. The core was removed from the protective core barrels, cleaned, logged in detail, and photographed, to provide a photo-record.

Representative core samples were removed for index and/or strength testing. The remaining core was then wrapped in plastic to prevent drying out and placed in core boxes for storage.

Index tests included moisture content, unit weight, specific gravity, soluble sulphate, Atterberg Limits, grain size analysis, and mineralogy. Mechanical tests included consolidation, unconfined compressive strength, tensile strength, point load strength, Schmidt Hammer Rebound Test, ultrasonic velocity, Mohs Hardness, slake durability, direct shear strength, and triaxial shear strength.

Summaries of the more important test results are presented in the following pages.

TABLE 5

SUMMARY OF SPECIALIZED GEOTECHNICAL FIELD TESTS

Type of Field Test	Summary of Field Test Results
Pressuremeter testing	. A total of nine pressure meter tests were performed in the Clearwater Formation. The maximum average total horizontal stress measured was 2.41 MPa at a depth of 106.6 metres. The deformation modulus ranged from 0.17 GPa to 5.0 GPa for primary loading for the nine tests done between 35.0 and 106.6 metres depth. The higher deformation modulus values were measured at the lower depths.
Westbay packer test	. Westbay equipment was designed to measure groundwater pressure and hydraulic conductivity within a short strata interval. Results of groundwater pressure measurements are shown in Figure 7. Hydraulic conductivities were measured but are not considered reliable because of poor hole conditions.
Gas exhalation	. Installed a gas well point in the McMurray Fm (interval 139.6 - 146.3 m depth) at hole AO16. . No measurable quantities of gas detected at surface when pressure was suddenly reduced at the well point.
Gas measurements	. Hardy Associates (1978) Ltd. estimated that the specific gas content of oil sand at the UTF ranged from 146 - 327 cm^3/kilogram of oil sand. Gas quantities were measured from oil sand core samples using the equipment and technique first developed for testing coal by the Coal Research Laboratories of CANMET.

Waterways Formation:

The Devonian sediments investigated at the site were categorized into four lithological types; massive limestone, argillacious limestone, interbedded limestone and shale, and calcareous shale. Table 6 presents the results of the unconfined compressive strength tests for the Waterways Formation sediments.

McMurray Formation:

Problems with gas exsolution from bitumen and associated destruction of the sand fabric in the core prevented the recovery of undisturbed oil sand samples for geotechnical testing. Disturbed specimens of McMurray Formation oil sands were therefore tested and the results of the unconfined compressive strength tests are presented in Table 7.

Reconsolidated samples of disturbed oil sand were frozen and tested in a triaxial apparatus under various confining pressures. The frozen compressive strength results are presented in Table 8.

The unconfined strength of the disturbed oil sand samples is very weak (Table 7). Freezing does not significantly increase the unconfined strength of the oil sand sample because of the low water content (the second test result in Table 8 demonstrates this point). The test results from Table 8 also show that the compressive strength of a frozen consolidated oil sand sample is increased significantly if a confining pressure is applied to the sample during testing.

Grain size analyses conducted on various samples throughout the McMurray Formation indicate a sand content ranging from 30 to 96 percent with a 4 to 70 percent fines content. Samples that were bitumen saturated had a low fines content; usually having a composition averaging 91% sand and 9% silt.

TABLE 6

COMPRESSIVE STRENGTH TEST RESULTS
WATERWAYS FORMATION

Lithology	Unit	Testhole	Depth (m)	Moisture Content (%)	Bulk Unit Weight (kN/m^3)	Compressive Strength (MPa)	Elastic Modulus E (GPa)	Poisson's Ratio v
Massive Limestone	Dwm	AO13	169.9	0.9	26.1	84.0	28.2	-
	Dwm	AO14	173.3	1.6	25.9	43.0	18.3	0.07
	Dwm	AO15	175.1	0.7	25.8	19.3	9.8	-
	Dwm	AO15	176.4	0.4	26.0	44.5	17.0	0.09
	Dwm	AO14	183.0	1.0	26.2	43.8	18.3	-
		Average		0.9	26.0	46.9	18.3	0.08
Argillaceous Limestone	Dwm	AO13	162.8	1.3	26.5	27.9	10.6	-
	Dwm	AO15	179.6	1.2	25.7	34.0	17.5	-
	Dwm	AO14	190.6	1.6	26.5	31.2	11.7	-
		Average		1.4	26.2	31.0	13.3	-
Limestone/Shale	Dwm	AO13	172.3	2.3	25.6	23.6	15.2	-
	Dwc	AO14	199.9	2.1	26.4	29.3	6.2	-
	Dwc	AO15	201.9	1.6	25.9	45.5	11.0	-
		Average		2.0	26.0	32.8	10.8	-
Calcareous Shale	Dwc	AO13	204.9	3.8	25.2	14.2	1.3	-
	Dwc	AO13	208.3	3.5	25.1	12.5	2.7	0.15
	Dwc	AO15	208.5	3.5	25.3	29.6	4.2	-
	Dwc	AO15	213.2	4.2	24.7	13.1	2.5	0.19
		Average		3.8	25.1	17.4	2.7	0.17

TABLE 7

COMPRESSIVE STRENGTH TEST RESULTS MCMURRAY FORMATION

Lithology	Unit	Testhole	Depth (m)	Moisture Content (%)	Bulk Unit Weight (kN/m^3)	Compressive Strength (kPa)	Failure Strain (%)	Elastic Modulus E (MPa)
Oil Sand	Km	AO15	141.2	7.8	21.2	1702.0	2.4	89
Oil Sand	Km	AO13	155.3	3.2	19.3	9.4	0.8	2.8
	Km	AO15	159.3	4.3	19.7	15.4	0.75	1.6
		Average		5.1	20.1	576.0	1.3	31.1

TABLE 8

COMPRESSIVE STRENGTH OF FROZEN OIL SAND

Lithology	Unit	Test Hole	Depth m	Consolidated (Cell) Pressure kPa	Initial Dry Unit Weight kN/m^3	Peak Deviator kPa	Strain at Failure %	Initial Water Content %	Final Water Content %	Bitumen Content %
Oil Sand	Km	AO15	135.7	1530	18.9	7300	3.1	7.0	6.7	6.02
Oil Sand	Km	AO15	145.7	0	19.1	387	1.3	0.5	0.4	16.41
Oil Sand	Km	AO15	161.3	1723	18.4	4040	3.8	1.13	1.08	19.02

Clearwater Formation:

The Clearwater Formation is predominantly a very weak claystone interbedded with very weak to moderately strong sandstone units and very weak to moderately strong siltstone units. The sandstone and siltstone zones are mostly found in the Kcw, Kcb, Kcd and Kcf units (Table 1). Unconfined compressive strength test results for the claystone ranged from 0.2 MPa to 3.0 MPa with an average of 1.1 MPa. The compressive strength results for the sandstone and siltstone units vary significantly due to differences in the cementing agent and the degree of induration.

Clay mineralogy analyses indicate that most of the clay-rich strata have only a minor smectite content. Low density intervals, which are expected to have a higher smectite content, indicate values in the 5 to 12% range across narrow intervals. One sample contained 18% smectite across a possible interval of 1.6 metres.

Grand Rapids Formation:

The Grand Rapids sediments range from predominantly dense fine grained sands through varying percentages of sand, silt and clay. The sands, silts and clays have low unconfined compressive strengths in the range from 0.07 to 1.1 MPa. There are several well indurated sandstone and siltstone beds having unconfined compressive strengths in the range of 36.8 to 80.6 MPa.

A-3 HYDROGEOLOGY

Tests were conducted to assess the hydraulic properties of most of the formations encountered at the site. In the majority of cases, rising head tests were carried out as an integral part of the piezometer development process. In addition, the four piezometers installed in hole AO-13, were tested by means of the falling head test method.

Standpipe piezometer installations AO8-P1, AO10-P2, AO16-P1, AO18-P2, AO20-P2, AO20-P3 have reached static equilibrium and the hydraulic conductivity results for those piezometers are considered reliable. Hydraulic conductivity values were not obtained for piezometer AO14-P1 and P2, AO15-P2 and AO17-P1.

Hydraulic conductivities (Table 11) obtained from the rest of the piezometer installations should be regarded with caution because either the static water level was not established (AO7-P1, AO9-P1, AO11-P1) or development of the piezometer was not completed prior to leaving the site.

Piezometer installation details for the geological and technical holes are summarized on Tables 9 and 10 respectively.

Site Conditions - Groundwater Chemistry

Piezometer development by displacing mud within the standpipe with compressed air preceded sampling in all instances to minimize sample contamination by cement grout and drilling mud. However, a combination of low hydraulic conductivities in many formations and the time constraints imposed by spring break-up precluded groundwater sampling in most of the aquifers. In all, five groundwater samples were extracted, two of which show strong indication of cement grout contamination. The results of the chemical analysis for the five groundwater samples extracted are presented in Table 12.

To supplement the groundwater quality information recently collected at site, analyses of water samples collected by Alberta Research Council from the observation wells located in the vicinity of the site were used to determine chemical characteristics.

TABLE 9

PIEZOMETER INSTALLATIONS AND TESTING - GEOLOGICAL HOLES

Hole No.	Piezometer No.	Depth m	Piezometer Type	Formation	Dates of Installation Completed	Dates of Development Start	Dates of Completion	Dates of Hydraulic Testing	Water Sampling	Notes
AO1										No Installation
AO2										No Installation
AO3										No Installation; drill stem sections left in the hole
AO4	A04-P1	161-169.1	38mm (1½ in.) Sch 80 pipe	Waterways (Dwm)	2-18-83	2-20-83	*	Feb 28/83	None	Very slow response
AO5	A05-P1	89.9/110.9	38mm (1½ in.) Sch 80 pipe	Clearwater (Kec, Keb)	2-23-83	2-25-83	*	March 1/83	None	Good response
AO6	A06-P1	128.0/135.0	38mm (1½ in.) Sch 80 pipe		2-21-83					Destroyed, probably during casing recovery
AO7	A07-P1	150.7/156.0	38mm (1½ in.) Sch 80 pipe	Waterways (Dwm)	2-17-83	2-17-83	*	2-28-83	None	
AO8	A08-P1	72.5/92.0	38mm (1½ in.) Sch 80 pipe	Clearwater (Kec, Ked)	2-15-83	2-16-83	2-23-83	2-23-83	Yes	
AO9	A09-P1	166.3/173.0	38mm (1½ in.) Sch 80 pipe	Waterways (Dwm)	2-18-3	2-20-83	*	2-26-83	None	
AO10	AO10-P1	124.4/137.0	38mm (1½ in.) Sch 80 pipe	McMurray (Km)	2-24-83	2-25-83	*	2-25-83	None	
	AO10-P2	59.5/65.0	19mm (3/4 in.) Sch 80 pipe	Clearwater (Kef)	2-24-83	2-25-83	2-28-83	2-28-83	Yes	
AO11	AO11-P1	155.6/163.2	38mm (1½ in.) Sch 80 pipe	Waterways (Dwm)	2-19-83	2-20-83	*	2-27-83	None	
AO12	AO12-P1	163.3/167.0	38mm (1½ in.) Sch 80 pipe		2-17-83					Destroyed, probably during casing recovery

Note: * Development not completed.

TABLE 10

PIEZOMETER INSTALLATIONS AND TESTING - GEOTECHNICAL HOLES

Hole No.	Piezometer No.	Depth m	Piezometer Type	Formation	Dates of Installation Completed	Development Start	Development End	Hydraulic Testing	Water Sampling	Notes
AO13	AO13-P1	193.6/210.3	19mm (3/4 in.) pipe	Waterways	2-24-83	2-26-83	*	2-26-83	None	
	AO13-P2	150.9/163.1	19mm (3/4 in.) pipe	McMurray	2-25-83	2-26-83	*	2-26-83	None	
	AO13-P3	80.0/87.8	19mm (3/4 in.) pipe	Clearwater	2-25-83	3-1-83	*	3-4-83	None	
	AO13-P4	57.4/67.5	19mm (3/4 in.) pipe	Clearwater	2-26-83	3-1-83	*	3-4-83	None	
AO14	AO14-P1	172.2/185.9	19mm (3/4 in.) pipe	Waterways	2-28-83	3-2-83	*	3-4-83	None	
	AO14-P2	120.4/125.9	19mm (3/4 in.) pipe	Clearwater	3-1-83	3-2-83	*	3-4-83	None	
AO15	AO15-P1	200.6/213.6	19mm (3/4 in.) pipe	Waterways	2-27-83	3-2-83	*	3-4-83	None	
	AO15-P2	120.7/140.0	19mm (3/4 in.) pipe	McMurray	2-28-83	3-2-83	*	3-4-83	None	
AO16	AO16-P1	139.6/146.3	63.5mm (2½ in.) pipe	McMurray	2-27-83	3-2-83	*	3-5-83	Yes	Gas well point
AO17	AO17-P1	125.9/131.0	63.5mm (2½ in.) pipe	McMurray	3-1-83					Incomplete grouting-abandoned
AO18	AO18-PN1	47.6/54.9	Pneumatic	Clearwater	3-1-83	N/A	N/A	N/A	N/A	
	AO18-P2	15.2/19.8	19mm (3/4 in.)	Grand Rapids	3-2-83	3-4-83	*	3-4-83	None	
AO19	AO19-PN1	87.8/101.2	Pneumatic	Clearwater	2-23-83	N/A	N/A	N/A	N/A	
	AO19-PN2	56.4/64.0	Pneumatic	Clearwater	2-23-83	N/A	N/A	N/A	N/A	
	AO19-P3	7.9/11.9	19mm (3/4 in.) pipe	Grand Rapids	2-23-83	N/A	*	3-4-83	None	
AO20	AO20-PN1	44.0/48.8	Pneumatic	Clearwater	2-28-83	3-2-83	N/A	N/A	N/A	
	AO20-P2	17.0/21.5	38mm (1½ in.) pipe	Grand Rapids	3-1-83	3-2-83	*	3-4-83	None	
	AO20-P3	4.4/7.4	19mm (3/4 in.) pipe	Grand Rapids	3-1-83	3-2-83	*	3-4-83	None	

Note: * Development not completed.

TABLE 11

SUMMARY OF HYDRAULIC CONDUCTIVITY VALUES (DETERMINED DURING RISING OR FALLING HEAD TESTS)

Hole Number	Formation	Interval Tested (m)	Hydraulic Conductivity (m/s)	Test Quality
AO20-P3	Grand Rapids and Quaternary	4.4 - 7.4	2.2×10^{-7}	Good
AO19-P3	Grand Rapids and Quaternary	7.9 - 11.9	3.4×10^{-10}	Not Satisfactory
AO18-P2	Grand Rapids	15.2 - 19.8	9.1×10^{-8}	Satisfactory
AO20-P2	Grand Rapids	17.0 - 21.5	1.2×10^{-7}	Good
AO10-P2	Grand Rapids	59.5 - 65.0	5.3×10^{-7}	Good
AO13-P4	Clearwater (Kcf)	57.0 - 67.5	2.4×10^{-10}	Not Satisfactory
AO13-P3	Clearwater (Kcd)	80.0 - 87.8	1.2×10^{-11}	Not Satisfactory
AO8-P1	Clearwater (Kcd & Kcc)	72.5 - 92.0	3.0×10^{-8}	Satisfactory
AO5-P1	Clearwater (Kcc & Kcb)	89.9 - 110.9	3.0×10^{-9}	Not Satisfactory
AO10-P1	McMurray	124.4 - 137.0	3.5×10^{-10}	Not Satisfactory
AO13-P2	McMurray	150.9 - 163.1	2.9×10^{-10}	Not Satisfactory
AO16-P1	McMurray	139.6 - 146.3	1.2×10^{-7}	Good
AO4-P1	Devonian (Dwm)	161.0 - 169.1	1.1×10^{-10}	Satisfactory
AO7-P1	Devonian (Dwm)	150.7 - 156.0	3.0×10^{-9}	Satisfactory
AO9-P1	Devonian (Dwm)	166.3 - 173.0	1.4×10^{-9}	Satisfactory
AO11-P1	Devonian (Dwm)	155.6 - 165.0	1.5×10^{-9}	Satisfactory
AO13-P1	Devonian (Dwc)	193.6 - 210.3	1.1×10^{-11}	Satisfactory
AO15-P1	Devonian (Dwc)	200.6 - 213.6	1.1×10^{-10}	Satisfactory

Note: Insufficient data are available from piezometers AO14-P1, AO14-P2, AO15-P2 and AO17-P1 to calculate hydraulic conductivity.

TABLE 12

RESULTS OF GROUNDWATER CHEMISTRY ANALYSES

Subject:

Results of Analysis:

Formation		Devonian (Dwm)		Clearwater	Grand Rapids	McMurray
Hole Number		AO7-P1	AO7-P1	AO8	AO10-P2	AO16
Date Sample Collected		83/02/26	83/3/06	83/2/25	83/2/28	83/3/5
Date Sampled Analysed		83/08/01	83/3/10	83/3/01	83/3/07	83/3/9
Sodium	mg/L	710	1010	619	279	9540
Potassium	mg/L	130	55	7.7	27	68
Calcium	mg/L	310	2.4	12	71	253
Magnesium	mg/L	0.34	1.6	3.4	22	211
Iron	mg/L	0.57	0.15	0.21	0.15	0.15
Manganese	mg/L	0.05	0.05	0.05	0.10	0.64
Sulphate	mg/L	73	53	190	213	11
Chloride	mg/L	370	604	205	82	15000
Carbonate	mg/L	96	744	24	1	1
Biocarbonate	mg/L	1	366	1086	696	2087
Fluoride	mg/L	0.64	1.1	0.66	2.4	0.50
Nitrate-N	mg/L	1	1	1	1	1
Nitrite-N	mg/L	1	1	1	1	1
Hydrogen Sulphide	mg/L	0.01	0.01	0.01	0.01	0.01
Hydroxide	mg/L	653	-	-	-	-
Total Hardness (as $CaCo_3$)	mg/L	775	13	44	268	1499
Total Alkalinity (as $CaCo_3$)	mg/L	2080	1540	930	570	1710
Total Disolved Solids	mg/L	2842	2651	1596	1039	26110
pH @ 20°C		12.28	9.93	8.38	7.71	8.02
Conductivity	mS/cm	6.30	3.65	2.30	1.60	31.5
Biochemical Oxygen Demand	mg/L	20	7	5	5	10
Chemical Oxygen Demand	mg/L	284	310	87	55	149
Specific Gravity		1.003	1.003	1.002	1.001	1.019

TABLE 12 (Continued)

RESULTS OF GROUNDWATER CHEMISTRY ANALYSIS

Subject:

Results of Analysis:

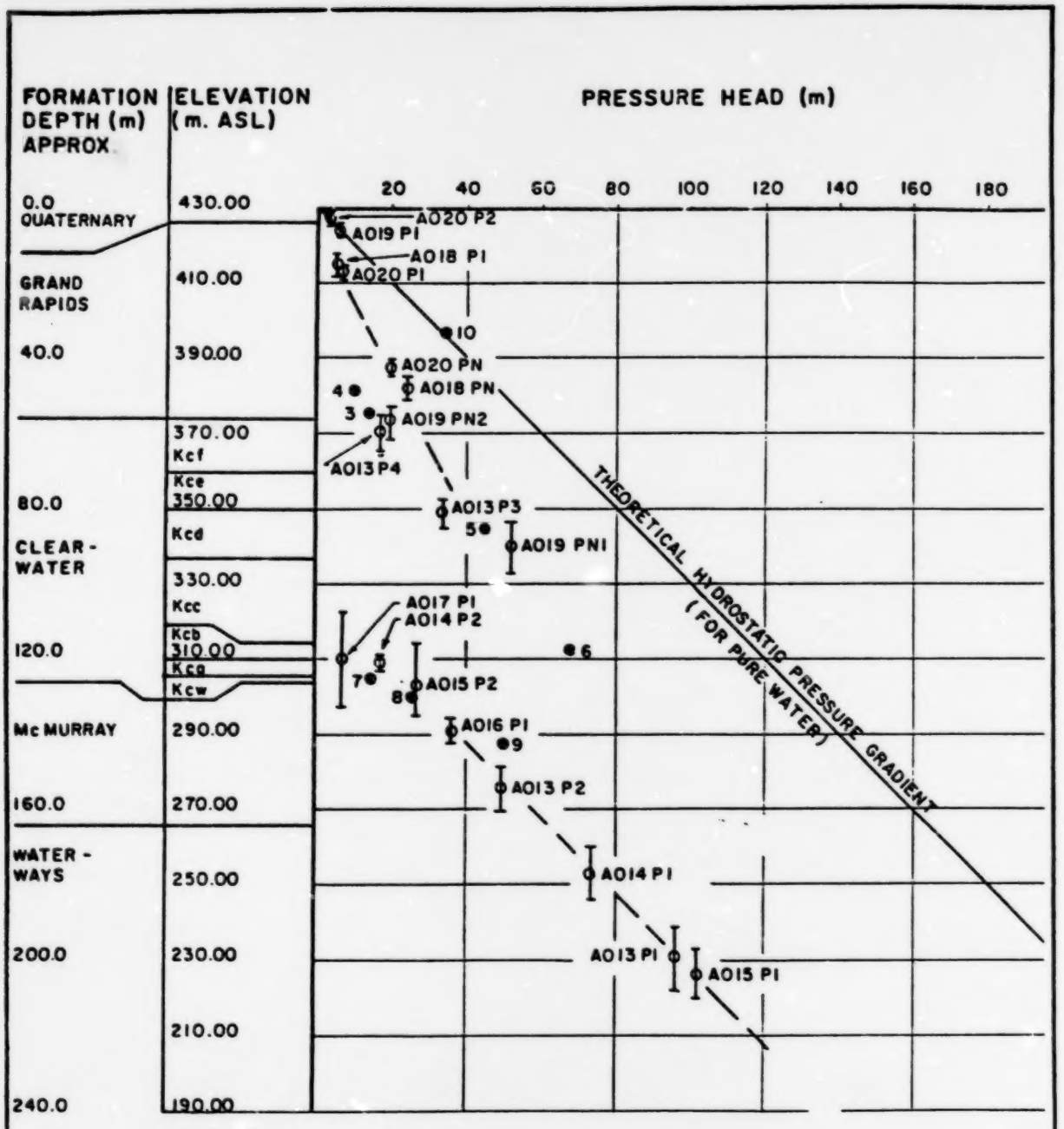
Formation		Devonian (Dwm)		Clearwater	Grand Rapids	McMurray[1]
Hole Number		AO7-P1	AO7-P1	AO8	AO10-P2	AO16
Date Sample Collected		83/02/26	83/3/06	83/2/25	83/2/28	83/3/5
Date Sampled Analysed		83/03/01	83/3/10	83/3/01	83/3/07	83/3/9
Aluminum	mg/L	.001	0.050	0.477	0.001	0.001
Arsenic	mg/L	0.01	0.02	0.01	0.01	0.02
Barium	mg/L	1.099	0.970	0.371	0.248	4.26
Beryllium	mg/L	0.012	0.029	0.009	0.004	0.054
Boron	mg/L	0.55	1.85	1.59	0.59	2.67
Cadmium	mg/L	0.0001	0.0001	0.0001	0.0001	0.0019
Chromium	mg/L	0.013	0.037	0.015	0.003	0.066
Cobalt	mg/L	0.098	0.280	0.077	0.020	0.458
Copper	mg/L	0.005	0.024	0.010	0.004	0.112
Iron	mg/L	0.13	0.13	0.17	.17	1.8
Lead	mg/L	0.001	0.001	0.001	0.001	0.001
Lithium	mg/L		NOT AVAILABLE			
Manganese	mg/L	0.015	0.038	0.091	0.093	0.154
Mercury	mg/L	0.0002	0.0002	0.0002	0.0002	0.0002
Molybdenum	mg/L	0.114	0.182	0.098	0.042	.386
Nickel	mg/L	0.033	0.166	0.030	0.007	0.301
Selenium	mg/L	0.001	0.001	0.001	0.001	0.001
Silicon	mg/L	0.001	0.001	0.001	0.001	1.493
Strontium	mg/L	0.197	0.188	0.174	0.192	0.187
Tellurium	mg/L		NOT AVAILABLE			
Tin	mg/L	0.101	0.322	0.029	0.008	1.047
Vanadium	mg/L	0.238	0.061	0.022	0.001	0.494
Zinc	mg/L	0.042	0.029	0.053	0.034	0.049

[1] Elevated trace metal content in the McMurray groundwater is probably related to the salinity and is not uncommon in sedimentary environments such as the McMurray Formation sands. The chemistry of McMurray Formation water indicates the probable incorporation of a significant amount of remnant sea water.

The groundwater quality data from the Alberta Research Council wells confirm the results that were obtained at site. Saline groundwater should be expected within the McMurray and Waterways Formation; Waterways having total dissolved solids (TDS) content of about 30,000 g/m^3 and the McMurray Formation having a TDS of 20,000 to 30,000 g/m^3. The Clearwater and Grand Rapids Formation contain brackish water having a TDS content less than 10,000 g/m^3.

Site Conditions - Groundwater Pressure

The water pressure profile with depth was determined from measurements of the water level in standpipe piezometers, from pneumatic piezometers and from packer tests during the drilling program. Figure 9 shows that the water pressure profile is much less than the theoretical hydrostatic pressure. This is possibly due to the existence of a drained layer which appears to be located near the Clearwater/McMurray boundary (possibly the upper marine sand of the McMurray and the Wabiskaw Member). It is expected that a few of the piezometers have not reached equilibrium conditions yet (those in the very low permeability areas, i.e. Devonian) and continued monitoring is being undertaken. Equilibrium conditions for these few piezometers will not change the hydrostatic pressure curve significantly from what is shown in Figure 7.



LEGEND

● PACKER TEST

⊕ PIEZOMETERS (VERTICAL BARS SHOW SCREEN DEPTH INTERVAL)

DEPARTMENT OF SUPPLY AND SERVICES
UNDERGROUND TEST FACILITY
PIEZOMETER DATA
DATE: JUNE 1985
SOURCE: E.R.C.B. Application
FIGURE: 7

APPENDIX B

PATENTS

APPENDIX B

4,076,311 Patent – US, Hydraulic Mining from Tunnel by Reciprocated Pipes

By Robert W. Johns, 1978

The invention relates to the Hydraulic Underground Mining of Bituminous Sands, oil shales and other mineral deposits. Accordingly, the invention resides in the provision of a tunnel complex at or near the base of the deposit, in which tunnels are driven parallel one with the other, and spaced a substantial distance apart. An exemplary distance would be in the region of 2,000 feet. Hydraulic excavators are driven outwardly from the sides of the tunnels until the excavator heads are in a position substantially midway between adjacent tunnels. The excavators are arranged in a multiple array at spaced intervals along the tunnels, these intervals being adjusted such that there is interaction during operation, between adjacent excavator heads.

The excavators may be positioned in two or more tiers by insertion into the deposit at differing angles from the operating tunnel, such that interaction between excavators is in two dimensions, horizontal and vertical. By systematic and programmed reciprocating movement of the individual excavators over a progressively enlarging "active zone", interacting between excavators is increased to three dimensions, horizontal, vertical, and lateral, thus effectively extending the "active zone" and increasing the volume of material being excavated. The ejector head, in addition to being provided with a multiplicity of nozzles through which fluid may be ejected at high pressure, also includes an intake or suction nozzle through which the fluidized sand, or slurry may be removed from the "active zone". The excavating nozzles are additionally spaced around the excavator head so that, at any time, certain nozzles are excavating below the intake nozzle to provide and evacuate a space into which oversized material can accumulate without plugging the intake. The nozzles being additionally spaced at predetermined angles relative to the excavator head so that they excavate both ahead of

the intake nozzle and laterally thereof. In this manner, the excavation is both advanced, and expanded laterally.

3,951,457, Patent - US, Hydraulic Mining Technique for Recovery of Bitumen from Tar Sand Deposit.

By D.A. Redford; Texaco Exploration Canada Ltd., 1973.

A hydraulic mining method for recovering viscous petroleum including bitumen from subterranean, viscous petroleum-containing unconsolidated mineral formations including tar sand deposits, said formation being penetrated at least one well, comprising.

1. Introducing a hot, aqueous hydraulic mining fluid containing an alkalinity agent into the formation via the wall in the form of a high velocity jet which rotates within the formation, said jet contacting the formation with sufficient energy to dislodge viscous petroleum and unconsolidated minerals.

2. Introducing a solvent for petroleum simultaneously with the aqueous hydraulic mining fluid.

3. Introducing a non-condensible gas into the formation.

4. Recovering a fluid pulp comprised of viscous petroleum unconsolidated minerals, solvent, and hydraulic mining fluid from the formation.

1,520,737 Patents - US, Method of Increasing Oil Extraction from Oil Bearing Strata

By W. Fisher, July 17, 1984 (37)

A versatile hydraulic mining/drilling system is proposed that includes modular units such as a hydraulic jet pump, a rock crusher, an auger-type drill bit, lateral and bottom slurry inlets with variable openings for feed rate control. All the above units can be mounted and operated independently or in combination within the same well bore in order to meet the different drilling conditions encountered in the same formation.

1,154,429 Patent - Canada, Method and Apparatus for Forming Lateral Passageways

By N.B. Dismukes, September 27, 1983 (50)

A neutral buoyancy horizontal drilling system is proposed whereby the drilling bit is activated by a hydraulic fluid circulated in a flexible pipe connecting the bit to the surface equipment. Both drilling bit and fluid have the same density range of 0.9 to 2.7 g/ml.

4,405,176 Patent - US, Method for Hydraulically Mining Unconsolidated Subterranean Mineral Formations Using Remote Support

By E.L. Hodges, September 20, 1983 (11)

To avoid subsidence of the overburden caused by underground cavity formed by hydraulic mining, the weight of the mining rig is evenly distributed over a large area by using spaced apart concrete pads and structural beams to support the rig. A hydraulic jet nozzle configuration is also disclosed that would create turbulent flow in the mined cavity to facilitate pumping of the slurry to the surface.

1,170,978 Patent - Canada, Modular Hydraulic Mining Tool and Improved Method of Hydraulically Mining a Mineral Formation

By R.L. Wright, December 30, 1924 (3)

In this mine-assisted process, a series of pipes extending radially outward and upward from an underground chamber are used to inject hot water and/or steam into the formation, and to collect the heated oil that drains into the chamber from which it is pumped to the surface.

4,479,541 Patent - US, Method and Apparatus for Recovery of Oil, Gas and Mineral Deposits by Panel Opening

By F.D. Wang, Elektra Energy Corp., October 30, 1984 (10)

The present invention comprises a method and apparatus which employs panel openings in place of a single or multiple drill holes for both primary and enhanced recovery (of bitumen and heavy oil). Because of large area of panel opening and even pressure therein, uniform flow can be obtained with high flow rate and recovery ratio.

1,169,353 Patent - Canada, Hydraulic Mining of Tar Sands

By H.S. Johnson, Gulf Canada Ltd., June 19, 1984 (22), US Patent 4,437,706

This patent proposes a hydraulic mining scheme that can be conducted near surface or underground, uses single or multiple jets, and rigid or flexible hoses for the jets. Separation of bitumen from oil sands is enhanced by the turbulent action of the jet, which can also contain an additive such as sodium chloride to further the separation.

4,283,088 Patent - US, Thermal Mining Method of Oil Production

By V.P. Tabakov, B.P. Kornev, L.N. Buchenkov, A.T. Gorbunov, V.E. Kaschavtsev, V.P. Pilatovsky, E.I. Gurov, A.I. Obrezkov, G.G. Vakhitov, R.T. Bulgakov, V.P. Maximov, R.A. Maxutov, A.I. Schnirelman, B.E. Dobroskok, K.A. Asfandiyarov, A.K. Fatkulln, August 11, 1981 (17)
Canada Patent 1,105,379

This patent proposes a mine assisted in situ bitumen recovery scheme that injects steam alternately into different groupings of strategically drilled wells so that oil flow direction can be altered and greater sweep could be achieved.

4,257,650 Patents - US, Method of Recovering Subsurface Earth Substances

By J.C. Allen, Barber Heavy Oil Process Inc. March 24, 1981 (14)

This invention relates to methods and systems for recovering high viscosity oils, petroleum and substances and other minerals from subsurface earth formations. In particular, one or more large diameter shaft holes are provided which preferably terminate in an enlarged subterranean chamber. A plurality of drill holes provided, with perforated piping which extend radially from the chamber into the formation, and from which oil and the like may be recovered. It is a particular feature of this invention to provide means and methods for injecting a mixture of steam and a noncondensable gas into the drill holes, whereby the driving mechanism of the formation may be selectively maintained or enhanced at the same time the viscosity of the oil in the formation is reduced. (author abstract).

4,234,232 Patent - US, Methods of and Apparatus for Mining and Processing Tar Sands and the Like

By C.D. Smith, DV. Keller Jr., Standard Oil Co. November 18, 1980 (8)

An underground oil sands mining method in which the mined sands are crushed and mixed with solvent to form a slurry which is pumped to an extration area where the bitumen-solvent mixture is separated from the mineral particles, then to a stripper where the solvent is recovered and recycled.

4,216,999 Patent - US, Machine for Mining Tar Sands Having Rearwardly Directed Exhaust Related to Conveyor Trough

By L. Hanson, August 12, 1980 (7)

A mining equipment design suitable for both surface and underground operations, its main feature being an adjustable cutting face with rotating heads to compensate for any change of direction in the tunnel. The mined materials are conveyed by a compressed air system.

1,048,926 Patent - Canada, Apparatus for Recovery of Hydrocarbons by In Situ Thermal Extraction

By R.P. Hendrick, February 20, 1979 (21)

An in situ process using layers of perforated horizontal wells radiating from a central shaft. The upper walls are heated and the formation oil is recovered as hydrocarbon vapors, which are partly condensed when they are circulated to the lower wells before entering a refining zone at the bottom of the shaft where they are fractionated. The fractions are then piped to the surface for further upgrading.

498,423 Patent - Canada, Extraction of Oil from Oil Bearing Sand

By M.W. Ball, Abasand Oils Ltd., January 9, 1945 (7)

This invention relates to the loosening and disintegration of oil sands in surface mining operations by exploding simultaneously charges of dynamite deposited in holes drilled in a predetermined pattern in the oil sands.

4,165,903 Patent - US, Mining Enhanced Hydrocarbon Recovery Technique

By J.H. Cobbs, August 28, 1979 (8)

A mine assisted in situ process where a horizontal shaft is drilled below the oil-bearing strata from a vertical access hole and wells are drilled upwards from one or more stations along the shaft into the formation to recover oil.

1,023,396 Patent - Canada, Monitor-Feeder/Breaker Combination and Method of Mining

By A.W.T. Grimley, Kaiser Resources Ltd., December 27, 1977 (22)

An underground hydraulic mining scheme with all the breaking, crushing, slurrying and conveying means incorporated in one single mobile unit.

1,020,176 Patent - Canada, Method of Driving a Mine Entry

By A.W.T. Grimley, Kaiser Resources Ltd., November 1, 1977 (15)

A shafting and tunnelling mining method where the crushed mined materials are mixed with water to form a slurry and the mixture is transported from the working area to the separation area by means of a flume.

1,063,012 Patent - Canada, Method of Recovery of Tar Sands Material

By C.H. Thayer, September 25, 1979 (50)

Injection-production wells are drilled at regular intervals and high pressure water jets are directed horizontally at the underground formation at predetermined sequence and directions to form interconnecting cavities within the oil sands body. The resulting slurry is pumped out for further separation.

1,063,011 Patent - Canada, Method of Recovery of Tar Sands Material

By C.H. Thayer, September 25, 1979 (53)

An underground hydraulic mining technique using a floating rig on a surface of water retained on dikes above a subterranean formation. A well casing is lowered from the rig and a hydraulic jet is used to carve layers of oil sand from the formation, the mined sand mixes with the injected fluid to form a slurry, which is then pumped to the water body at the surface to be separated.

1,053,572 Patent - Canada, Process for Recovery of Carbonaceous Materials from Subterranean Deposits by In Situ Processing

By M.A. Lekas, May 1, 1979 (22)
US Patent 4,037,657

Subterranean carbonaceous deposits, such as oil shale or the like, that are located at or close to the surface, are prepared for retorting by drilling blast holes from the surface into the deposit, and blasting, creating a rubble pile that reaches the surface. The surface is sealed by suitable means, and the oil shale is retorted in place. Where a stratum of barren rock lies between the carbonaceous deposit and the surface, the blast holes are drilled and blasted in such a manner as to maximize the fragmentation of the carbonaceous deposit, and minimize the fragmentation of the overlaying barren stratum. Where overburden conditions are not suitable for treatment

by this method, the overburden is removed by strip mining methods, and the carbonaceous deposits are exposed for treatment by the method described above. (author abstract).

4,113,036 Patent - US, Laser Drilling Method and System of Fossil Fuel Recovery

By D.W. Stout, September 12, 1978 (11)

Underground bores are drilled through a formation from a plurality of vertical bore holes by use of laser beams to form a subsurface, three-dimensional bore passage pattern for in situ preparation of fossil fuel deposits to be recovered. A laser beam is projected vertically through an angularly adjusted tubular housing inserted into each bore hole from which a reflected drilling beam is laterally directed by an angularly adjusted reflector to form a bore passage. (author abstract).

4,099,783 Patent - US, Method of Thermoshaft Oil Production

By V.G. Verty, P.G. Voronin, E.I. Gurov, V.S. Zubkov, N.I. Melnichuk, G.G. Miller, V.N. Mishakov, V.S. Sukrushev, L.M. Ruzin, V.P. Tabakov, July 11, 1978 (6)

The method for thermoshaft oil production comprises the provision of a combination of mining holes above an oil-bearing bed which are inclined at from 1 degree to 3 degrees to the horizon. Then injection holes are drilled from these mining openings for feeding a heating medium into the bed. After that, a slope and a footway leading to the bottom part of the oil-bearing bed are constructed, and a production gallery is provided within the bottom part of the bed. Horizontal and ascending holes are drilled from the production gallery for oil production. A heating medium is fed into the injection holes for uniform distribution thereof over the entire volume of the oil-bearing bed and for displacement of oil into the horizontal and

ascending production holes towards the production gallery wherefrom the oil is fed up to the surface. (author abstract).

1,035,797 Patent - Canada, In Situ Methods of Extracting Bitumen Values from Oil-Sand Deposits

By L.C. Rabbits, August 1, 1978 (58)

In the method of this invention, an access shaft is driven into the oil sands and an access drift is driven below the oil sands body from which a hot fluid and/or fluid bitumen mixture may be fed to and/or removed from the oil sands body. The mixture of fluid and bitumen is removed through perforated pipes and separated. The invention involves a room-and-pillar method of mining, the pillars acting as barriers between adjoining rooms.

4,101,172 Patent - US, In Situ Methods of Extracting Bitumen Values from Oil Sand Deposits

By L.C. Rabbits, July 18, 1978 (20)

The present invention provides a method of in situ extraction of bitumen from an oil sands body which method comprises sinking an access shaft through the oil sands body, driving an access drift in the rock strata underlying the oil sands body, delineating a rectangular block of oil sands in said body by drilling and blasting the oil sands body to provide substantially vertical planes of fractured oil sands on all four sides of an enclosed mining room capable of retaining liquids and gases under pressure and comprising solid pillar walls, providing generally upwardly extending bores in said block of oil sands from the access drift in the said body, providing perforated pipes in those portions of the bores in said block, the perforations of said pipes being dimensioned to prevent sand particles from said block passing therethrough, increasing the permeability of the block of oil sands within said room by fracturing said block, flooding the mining room with a hot

fluid at a temperature of the block by an amount to cause the bitumen to become flowable with said fluid and removing the fluid-bitumen mixture so formed from said block, the passage of said fluid through said being via said perforated pipes and separating said bitumen from said fluid. (author abstract).

1,038,411 Patent - Canada, Method for Mining Oil Shales, Tar Sands and Other Minerals.

By R.W. Johns, September 12, 1978 (31)

A laterally extending underground mining face is formed at the base of an oil shale or tar sand ore block. Against the mining face a mining shield, consisting of a plurality of individual arch sections, is placed. The ore is mined by advancing each arch into the deposit. Behind the mining shield the ore is unsupported and allowed to collapse. After the mining has proceeded an optimum distance, the direction is reversed to operate on the collapsed material. This process is repeated until the entire ore block has been mined.

4,003,441 Patent - US, Method of Opening Carbon-Bearing Beds with Production Wells for Underground Gasification

By E.L. Lokshin, A.F Volk, A.A. Starinksy, January 18, 1977

A method for drilling production wells into carbon-bearing beds to be recovered by underground gasification is given. The well is drilled until the top of the bed is reached and a short distance thereinto.
Gamma-ray logging is used to determine the exact depth of the top of the bed. Drilling is continued to a depth where communication between adjacent wells by a fluid is assured, leaving a pillar between the drill bit and the bottom of the bed, and the well is completed with a cemented casing. The pillar remaining is drilled using water or a gaseous agent.

4,067,616 Patent - US, Methods of and Apparatus for Mining and Processing Tar Sands and the Like

By C.D. Smith, D.V. Keller Jr, Standard Oil Co., January 10, 1978 (8)

An oil sand recovery method is proposed whereby the oil sand is mechanically dislodged underground without disturbing the overburden, preferably using augers such as those used in coal mining, and mixed with a fluorocarbon solvent to lower the viscosity for ease in transport to the separation operation. The auger is modified to contain a hollow shaft and nozzles at the forward end to supply the solvent for mixing with the dislodged oil sands.

4,037,657 Patent - US, Process for Recovery of Carbonaceous Materials from Subterranean Deposits by In Situ Processing

By M.A. Lekas, July 26, 1977 (8)

This invention provides a method for in situ recovery by retorting of oil shales and like deposits located in surface and near surface formations. An array of blast holes is drilled into the formation and a rubblized zone of shale is formed by blasting to expand the material upward. The earth surface over the rubblized formation is sealed and inlet and outlet conduit means are provided to the floor of the rubblized zone. Air is injected to initiate and control combustion. Where the overburden would prohibit such rubblization it may be first removed by strip mining.

1,026,387 Patent - Canada, Hydraulic Mining of Oil Shales, Tar Sands and Other Minerals

By R.W. Johns, World Oil Mining Ltd., February 14, 1978 (36)

A method for the underground hydraulic mining of oil sands and oil shales is proposed. A series of parallel tunnels are driven into the base of the

deposit. From the sides of these tunnels hydraulic excavators are driven outwardly in a systematic pattern. The excavators have an ejector head, through which fluid is ejected at the deposit at high pressure, and intake nozzles, which suck up the fluidized sand or slurry. The slurry is pumped from the workings.

1,021,889 Patent - Canada, Hydraulic Mining of Oil Bearing Formation

By C.A.R. Lambly, C.T. Draney, Bechtel International Corp., November 29, 1977 (28)

1,018,556 - Canada, Method of Removing Tar Sands from Subterranean Formations

By C.A.R. Lambly, C.T. Draney, Bechtel International Corporation October 4, 1977 (23)

1,023,397 Patent - Canada, Hydraulic Mining Method

By R.W. Johns, World Oil Mining Ltd., December 27, 1977 (32)

986,146 Patent - Canada, Apparatus and Method for Mining Tar Sands, Oil Shales and Other Minerals

By R.W. Johns, World Oil Mining Ltd., March 23, 1976 (58)

986,544 Patent - Canada, Method of Mining Oil Shales, Tar Sands and Other Minerals

By R.W. Johns, World Oil Mining Ltd., March 30, 1976 (15)

3,960,408 Patent - US, Tunnel Layout for Longwall Mining Using Shields

By R.W. Johns, World Oil Mining Ltd., June 1, 1976 (31)

This invention relates to a system for underground mining of friable mineral materials. A mining shield comprising a plurality of arch sections extends between a pair of parallel operating tunnels horizontally spaced adjacent the base of a working block of mineral deposits. The arch sections are arranged in side-byside arrangement, free of any permanent interconnection, and comprise a floor-forming base portion and a cantilever portion extending upwardly from the base at a generally acute angle to form a roof. An operator's pulpit is positioned in each of the operating tunnels at the end of the mining shield. The shield houses mining equipment which is movable from one end of the shield to the other and which can make a mining cut while moving, and also means for conveying mine material to one of the tunnels. Means are provided for advancing the shield as the mining equipment forges into a cut and for removing detrital from the spaces into which the shield is to be advanced.

3,958,830 Patent - US, Longwall Mining System and Archshield for Mining Tar Sands, Oil Shales and the Like

By R.W. Johns, World Oil Mining Ltd., May 25, 1976 (32)

A novel mining shield is described which comprises a plurality of forwardly inclined, base supported arch members positioned in adjacent abutting relationship and each independently advanceable towards the mining wall. As a cut is removed, the individual arch sections are advanced forwardly into the cut leaving an unsupported wall, posterior of the shield, which gradually collapses.

3,797,590 Patent - US, Underground Mining System

By W.R. Achibald, J.J. Gilbert, Marcona Corporation, March 16 1974 (9)

4,502,733 Patent - US, Oil Mining Configuration

By J.R. Grubb, Tetra Systems Inc., March 5, 1985 (13)

The invention relates to an oil mining configuration intended for use as a production drift for the recovery of petroleum from an overlying, oil bearing formation by gravity drainage. The configuration has a shape of a lollipop when viewed from above; two methods of forming the lollipop drift are given. Production wells are drilled upwardly from the drift and the produced oil, gas and water are pumped to the surface.

APPENDIX C

ANNOTATED BIBLIOGRAPHY

ANNOTATED BIBLIOGRAPHY

Attached is a complete listing of papers obtained from the literature search. The listing includes a brief description of the possible relevance each paper's content may have to the project.

The papers are categorized into the following topic headings:

Base Data

Includes papers with relevant information that is specific to the Athabasca area.

Mining Concepts

Papers that discuss or review various proposed recovery projects.

Monitoring/Drilling

Papers that discuss monitoring and/or drilling methods.

Hydraulic Mining

Papers discussing the technology or theory associated with hydraulic mining or jet piercing.

Hydraulic Fracturing

Papers discussing theory, tests or discussion of hydraulic fracturing techniques.

Blasting

Papers reviewing tests or theory related to permeability enhancement through explosive fracturing.

Safety

Papers specifically addressing relevant safety issues.

Associated Information

Other papers that cannot be categorized in the previous groupings.

In addition, each of the categories are further broken into three levels of interest;

Primary - the paper as a whole is relevant to the study.
Secondary - only a portion of the paper may be relevant to the study.
Tertiary - supplemental information that may or may not prove useful in the study.

ANNOTATED BIBLIOGRAPHY

BASE DATA - PRIMARY (BD-P)

Brooker, Devenny and MacRae.

1978: **Deep Excavation in Oil Sand - Why, Where, How?**

Presented to AOSTRA Seminar on Underground Excavation in Oil Sands. U. of A., Edmonton, Alberta, Paper No. 12, 23p.

Good discussion on potential problems of excavation, tunnel support in tar sands due to geology, material characteristics and strata change due to heating.

Devenney, D.W. and Raisbeck, J.M.

1980: **Rock Mechanics Considerations for In Situ Development of Oil Sands.**

Presented to 13th Canadian Rock Mechanics Symposium, Toronto. Canadian Institute of Mining and Metallurgy, special volume 22, p. 90-97.

Decribes the MAISP concept and requirements for design for the openings, induced fracture systems and rock properties and behaviour under a range of in situ environments.

Golder Associates.

1979: **Investigation of Waterways Formation Limestones.**

Prepared for Energy, Mines and Resources Canada Center for Mineral and Energy Technology, Calgary, Alberta, Contract 77-9121.

Includes summary and conclusions sections of the report.

Hackbarth, P.A.

1978: **Hydrogeological Concerns in Underground Excavation, Athabasca Oil Sands Area.**

AOSTRA Seminar on Underground Excavation in Oilsands, U. of A., Edmonton, Alberta, 36p.

General hydrogeology of tar sands including estimates of expected waterflows, discontinuities and hydraulic pressures. Brief information on gases. Good information in questions section at end of paper.

Hardy, R.M. and Scott, J.D.

1978: **The 1963 G.C.O.S. Test Shaft.**

A paper prepared for inclusion in the Proceedings of the AOSTRA Seminar on Underground Excavation in Oil Sands, Edmonton.

Gives an actual hands-on description of the properties of the oilsands. Relevant to tunneling in this medium.

Hardy, R.M. Associates and Hatch Associates Ltd.

1977: **Feasibility Study for the Underground Mining of Oil Sands.**

Prepared for Energy, Mines and Resources Mining Research Center, Calgary, 118p.

Summary of expected conditions in Athabasca oilsands and behaviour of material.

Harris, M.C. and Sobkowicz, J.C.

1978: **Feasibility Study of Underground Mining of Oil Sand.**

Prepared for AOSTRA Seminar on Underground Excavation in Oilsands, U of A Edmonton, Alberta.

Paper summarizing the report to EMR in 1977 on the feasibility of U/G mining in oil sand. Discussed geology, and hydrogeological implications with respect to mining, various U/G mining techniques and in situ mine assisted methods, some cost information on mining and a proposed research program.

Harris, M.C., Poppen, S. and Morgenstern, N.R.

1979: **Tunnels in Oil Sand.**

As printed in the Journal of Canadian Petroleum Technology, vol. 18, No.4.

Assesses tunnel construction in Oil Sand based on the Saline Creek project, natural exposures, man-made excavations and a review of available literature.

Heald, B.D.

1983: **A Geotechnical Investigation of the Devonian Waterways Formation at the Sandalta Lease.**

Masters Thesis submitted to Facility of Graduate Studies and Research, U of A, Edmonton, Alberta. 375p.

Documents geological and geotechnical features of the upper Devonian Waterways Formation with respect to mining ventures in the Athabasca Oilsands. Very detailed document. Areas of interest include discussion of horizontal stresses, collapse features, fluvial channels, hydrogeological effects and, temperature-pressure effects.

Mathews, K.E, Rawlings, G.E. and Bharti, S.

1980: **Investigation of the Geotechnical and Mining Characteristics of the Devonian Limestones Athabasca Oil Sands Area.**

Paper presented to Applied Oil Sands Geoscience Conference, Edmonton, Alberta.

Studies the geotechnical and mining characteristics of Devonian Limestone with a view towards their development as a means of access for mining. Includes testing of rock samples and design recommendations.

Mossop, G.

1978: **Geological Controls on Reservoir Heterogeniety - Athabasca Oil Sands.**

AOSTRA Seminar on Underground Excavation in Oilsands, U of A, Edmonton, Alberta, 27p.

Discussed deposit characteristics, stratigraphic and depositional setting, petrology and reservoir configurations. Not site specific but good information of area characteristics.

Norwest Resource Consultants.

1983: **Application for Approval of an Experimental Underground Shaft and Tunnel Access Scheme in Oil Sands;** v. 1 of 2. Prepared for AOSTRA.

Specific information on the AOSTRA test site including geology, geotechnical, hydrogeology, underground access layouts, designs, in situ recovery method and safety measures.

Raisebeck, J.M. and Currie, J.B.

1979: **In Situ Oil Sands Geotechnique.**

Presented at the Fourth University - Industry Oilsands Research Seminar, Fort McMurray.

Reviews the current state of the art on engineering geology and the physical properties required for hydraulic fracturing of the oilsands and mine assisted in situ processing techniques.

Roesner, E.K., and Poppen, S.A.

1978: **Shaft Sinking and Tunnelling in the Oil Sands of Alberta.**

AOSTRA Seminar on Underground Excavation in Oilsands, U. of A, Edmonton, Alberta.

Some discussion of shields required for in situ tar sand tunnels.

Rogers, G.

1978: **Geological Aspects of Saline Creek Tunnel.**

AOSTRA Seminar on Underground Excavation in Oilsands, U. of A., Edmonton, Alberta.

Very detailed discussion of predicted and observed geology of the tunnel. Very site specific information.

Scott, J.D. and Kosar, K.M.

1984: **Geotechnical Properties of Athabasca Oil Sands.**

Presented at WRI-DOE Tar Sand Symposium, Vail, Colorado.

A key paper outlining up to date detailed getechnical properties of tar sands.

Scott, J.D., Eisenstein, Z., and Branco, P.

1985: **Geotechnical Aspects of Construction and Operation of the Mining Access Concept.**

Paper prepared and presented to the AOSTRA Seminar on Advances in Petroleum Recovery and Upgrading Technology. Edmonton, Alberta.

Discusses parameters which must be evaluated in the design of shaft and tunnels for both the initial in situ conditions and the change in conditions caused by the in situ bitumen recovery operations.

Scott, J.D.

1978: **Summary to the Seminar and Closing Remarks.**

General reports on the AOSTRA Seminar on Underground Excavation in Oilsands. U. of A., Edmonton, Alberta.

Includes a good brief review of present state of knowledge on oil sand properties related to U/G excavation. Also summarizes other papers presented at the conference.

Smith, L.B.

1978: **Construction of Saline Creek Tunnel in Athabasca Oil Sand.**

AOSTRA Seminar on Underground Excavation in Oilsands. U. of A., Edmonton, Alberta.

Covers geology, design and construction in oil sand. Essential reading to gain knowledge of the limited actual experience underground in oil sand.

Smith, L.B. and Byrne, P.M.

1980: **Conveyance - Confinement Method of Design for Shafts and Tunnels in Oil Sands.** Paper presented to the conference on Applied Oilsands Geoscience, Edmonton.

Discusses the application of the conveyance - confinement method to estimate stand-up time and short and long term loads on ground support.

Stephenson, H.G.

1978: **An Evaluation of the Underground Approach to Oil Sand Development.**

AOSTRA Seminar on Underground Excavation in Oil Sands.
U. of A., Edmonton, Alberta.

Discusses comparative economic advantages of MAISP versus underground mining with surface processing. Mentions tunnel design must take into account stress from blasting if used.

Stephenson, H.G. and Owen, H.

1983: **The AOSTRA "Underground Test Facility" An Update– August, 1983.**

Paper prepared for CIM District Five Meeting, Calgary.

Directly applicable and site specific if we are to assume using this facility for the experiments.

Williams, K.A., Stimpson, B., Patching, T.H. and Jeremic, M.L.

1980: **Rock Mechanics Properties of the Waterways Formation.**

Presented at the Alberta Oilsands Conference, Edmonton.

A summary on a masters thesis conducted by Williams on the rock mechanics properties of the Devonian Waterways formation. Mainly applicable to underground mining.

Base Data - Secondary

Brooker, E.W.

1980: **Geotechnical Frontiers in Oilsand Mining.**

Paper delivered at IMEC '80, Calgary.

General overview of the state of geotechnical knowledge for surface and subsurface mining and/or recovery of tar sands.

Rennie, J.A.

1983: **Applied Geology- Key to Mining the Athabasca Oil Sands.**

Presented at CIM First District Five Meeting, Paper No. 42.

Discusses the depositional characteristics of the Sandalta oilsands deposits and presents a computerized method for evaluating the geological data base.

Towson, D.E.

1984: **The Mine Assisted In Situ Project.**

Presented at the fith annual "Advances in Petroleum Recovery and Upgrading Technology" Conference, Calgary, Alberta.

A generalized description of the MAISP project. Moderately useful for reference of what has been conducted to date and in understanding some of the parallel problems we are expecting.

Mining Concepts - Primary

Barr, P.K. and Rasku, R.R.

1983: **A Case for Underground Oil Mining in Canada.** As presented at the CIM District Five Meeting. Calgary, Alberta.

Addresses the scheme for extracting light crude oil in today's economic climate. Reviews a conceptual study and its economics. Quite general.

Charleswood, R.G., Bryne, P.M., McKenlay, D.W. and Varoglu, E.

1980: **Thermal Geomechanical Analyses for the Design of a Mine Assisted Heavy Oil Recovery Facility.** Prepared for presentation at Applied Oilsands Geoscience Conference. Edmonton, Alberta.

A general design concept presented for a facility to provide underground access for injection and production from either the limestone or oilsands. The geotechnical aspects are relevant. Computer simulated models and programs are discussed.

Dick, R.A. and Wimpfen, S.P.

1980: **Oil Mining.** Scientific America, V. 243 N. 4., October 1980. p. 182-188.

A general description with good illustrations of some of the more promising underground in situ methods of mining tar sand. Discusses block caving, gravity drainage and pumped drainage.

Fuel and Mineral Resources, Inc.

1984: **Detailed Technical and Economic Feasibility of Light Oil Mining in the United States.** Technical Information, U.S. Department of Energy, Contract No. AC19-82B10704.

Discusses conceptual methods of underground mining including drilling, some blasting, chemical explosives fracturing and other explosive fracturing methods. Also discusses Block Caving and lateral drilling or horizontal collection boreholes from tunnels. Substantial cost estimate (detailed) info. Formula for formation heating by steam injection (see page 3-54). A good reference source.

Haston, J.A.

1978: **Mine-Assisted In Situ Processing.** Paper No. 4 - AOSTRA Seminar on Underground Excavation in Oil Sands.

Good paper discussing comparison of possible horizontal drilling in situ. MAISP prospects in Athabasca tar sands using comparisons to Yarega experience in Russia.

Horkoff, C.T.

1982: **Evaluation of Bitumen Resource Development Utilizing Horizontal Wells Drilled from the Surface or from Underground Tunnels.** 2nd Int. Conference on Heavy Crude and Tar Sands, Caracas, 7-17 February 1982. p. 903-906.

Basically a very brief discussion of the Surmont Project of Gulf and AOSTRA, its general project direction and design consideration.

Mathews, K.E.

1980: **Potential for the Underground Mining of Oil Sands in Canada.** Paper presented to Rockstore 80, proceedings of the International Symposium on Subsurface Space for Environmental Protection, Stockholm, Sweden.

Reviews the potential for the mining of oil sands by hydraulic and in situ methods using the underlying limestone formations for access. Excellent summary of relevant projects.

Patching, T.H, Jeremic, M.L., Stimpson, B.

1978: **On the Possibility of Mining Oil Sand by Underground Methods** AOSTRA Seminar on Underground Excavation of Oilsands, Edmonton, May 1978.

General discussion of surface versus various underground mining techniques. Suggests Block Caving has best underground potential. Not much specific information. Brief discussion of hydraulic mining.

Rompetrol, Dr. A.

1985: **Oil Production by Mining in Romania.** Paper prepared for the Aostra Seminar on Advances in Petroleum Recovery and Upgrading Technology, 1985, Edmonton.

This paper gives a brief outline of the history, since 1925, of Romanian oil production by mining.

Mining Concepts - Secondary

Energy Development Consultants/Stone and Webster Engineering

1983: **An Evaluation of Heavy Oil Mining - Final Report.** v. II. Prepared for U.S. Department of Energy (Contract #D.E. - ACO3-80PC 32259).

Portions of the report may be of interest. These are listed below.

Discussion of Underground Mining Methods
- includes section on hydraulic mining

Safety
- discussion on H_2S containment, concern of gases with lower flash points than methane requiring special requirements for diesel and electrical systems.

Firefighting and oil affecting electrical services.

Mine gases, TLV's, upper and lower explosion limits.
- includes considerable cost estimation.
- tables include explosive and TLV limits of various hydrocarbons.
- gives formula for calculation of oil production rates for gravity drainage.
- gives extensive discussion of methods and costs of Gravity drainage with Thermal assistance.

Flock, D.L. and Tharin, J.

1975: **Unconventional Methods of Recovery of Bitumen and Related Research Areas Particular to the Oil Sands of Alberta.** Paper presented at 26th Annual Technical Meeting of Petroleum Society of CIM, Banff, Alberta.

Lists various unconventional methods of recovery of Tar Sand. Touches on hydraulic and underground methods but is quite out of date. Some points appear to be quite relevant.

Richings, M.B.

1983: **Oil Mining Review.** Paper for seminar on "Oil Mining", CIM District 5 Annual Meeting, Calgary, September 7-9, 1983.

Current technologies are discussed with the main emphasis on underground drainage methods. References to Golders and Energy Div. Consultants studies are made. Some mention made regarding economics but overall is very general.

Sanceire, Z.A. and Jerisic, N.

1982: **Hydraulic Mining Process for Extra Heavy Crudes.** 2nd Int. Conference on Heavy Crude and Tar Sand, Caracas, February 7-17, 1982. p. 1065-1068.

Discusses a process of hydraulically injecting fluids into the formation via drill holes at enough pressure to lift the overburden. The pressure is released and as the overburden falls it ejects a fluid, oil sand slurry out of the well over a two minute period. Gives theoretical formula to calculate crack width.

Smith, G.W. and Butler, R.M.

1979: **Studies on the Use of Tunnels and Horizontal Wells for Recovery of Heavy Crude.** As published by the Alberta Oil Sands Information Centre. 1st Int. Conference on the Future of Heavy Crude and Tar Sands, Edmonton, June 4-12, 1979.

A general discussion on the UTF concept and of some of the expected costs.

Spence, W.P. and Hyland, M.J.

1983: **Is Oil Mining Becoming Attractive?** Reprinted from Petroleum Engineer International, V. 55, N. 5, April 1983, p. 96, 98, 100.

General discussion on underground mining of oil sands.

Surguchev, M.L.

1983: **Recovery of Hydrocarbons from Oil Sands and Oil Shale by Mining.** Reprint of the Eleventh World Petroleum Congress, London, August 28, 1983.

General review of thermal in situ recovery processes discussed in other papers. No new information. Short, summary review.

Vladut, T.

1983: **Mining Oil: Considerations for Underground Access.** Presented to the session on Oil Mining, CIM, District 5 Annual Meeting, Calgary. Paper No. 31.

Good paper briefly covering the main issues of underground oil mining relevant to Canada. Lacks detail on certain areas. Addresses most of the UTF related questions.

Mining Concepts - Tertiary

Dick, R.A. and Wempfen, S.P.

1980: **Oil Mining.** As appeared in Scientific American, V. 243, N4, p. 182-188.

A generalized discussion on the potential of mining oil in the U.S. with reference to Yarega, U.S.SR. Outlines some ideas which may be of use. Also considers fan drilling techniques. Shaft and tunnel schemes similar to UTF.

Energy Development Consultants.

1983: **An Evaluation of Heavy Oil Mining - Final Report, V. 1,** For U.S. Department of Energy. (Contract # DE AC03 80PC 30259).

Discusses MAISP techniques but not in detail. Primarily concerned with site selection.

Marchant, L.C. and Koch, C.A.

U.S. Tar Sand Oil Recovery Projects. Chapter 107 of Heavy Crude and Tar Sands, p. 1029-1040.

A general listing of all U.S. tar sand projects and the status of each. A good reference list.

Readdy, L.A. and Skyllengstad, P.

Evaluation of the Kern River Oil Field as a Potential Candidate for Mining Oil. Chapter 110 of "Heavy Crude and Tar Sands". p. 1069-1075.

Discusses geology of Kern River and the process followed to gather information to evaluate the deposit for open pit mining.

Quinn, P.C. and G. Duncan.

1979: **The Mine Assisted In Situ Project.** 1st Int. Conference on the Future of Heavy Crude and Tar Sands. Edmonton, Alberta, June 4-12, 1979.

Mainly discusses drilling techniques applicable to MAISP type facility and a program which was developed to test these techniques through a outcrop site in the Athabasca River Valley.

Stosur, J.J. and Lievens, E.J.

1982: **Heavy Oil and Tar Sand Research and Development at the U.S. Department of Energy.** 2nd Int. Conference on Heavy Crude and Tar Sands, Caracas, February 17, 1982.

Listing of E.O.R. processes and projects with the outlook for future development.

Monitoring/Drilling - Primary

Bohme, C.G. and Strickland, A.

1985: **Drilling Oilwells from Underground.** Paper prepared for the AOSTRA Seminar on Advances in Petroleum Recovery and Upgrading Technology, Edmonton, Alberta.

Dusseault, M.B. and Scott, J.D.

1984: **Coring and Sampling in Heavy Oil Exploration.** Paper presented at AAPG Research Conference on Exploration for Heavy Crude Oil and Bitumen, Santa Maria, California.

Discusses coring techniques at various depths in tar sands and properties that can be accurately measured from the cores and properties that are disturbed by coring. Proposes improved drilling methods.

Dusseault, M.B. and Van Domselais, H.R.

1982: **Unconsolidated Sand Sampling in Canadian and Venezuelan Oil Sands.** Presented at Second International Conference on Heavy Crudes and Tar Sands, Caracus, Venezuela.

Discusses problems with current oil sand coring techniques and proposes improved methods.

Jones, A.H., Sinha, K.P. and Abou-Sayed, A.S.

1980: **A Review of a Hydraulic Fracture Test in the Tar Sands at Asphalt Ridge, Utah.** Presented at "Tar Sands Permeability Enhancement" Workshop, Albequerque, New Mexico.

Discusses a site specific evaluation of a hydraulic fracture test. Includes all the concerned properties of the property, design of the fracture, and methods of fracture mapping.

McFall, A.L.

1980: **Directional Drilling in Tar Sands.** Presented at Tar Sands Permeability Enhancement Workshop, Albequerque, New Mexico.

Summarizes the horitonal drilling experiences and discusses the problems that can arise in drilling tar sands.

Patterson, M.A., Ruthbert, L.G., Tremble D.

1985: **Blind Boring Through Oil Sands - A Trail Blazer.** Prepared for the AOSTRA Seminar on Advances in Petroleum Recovery and Upgrading, Edmonton, Alberta.

Discusses the shaft sinking procedure used for the activities at the AOSTRA UTF site.

Reynolds, J.J., Scott, J.B., Bopham, J.L. and Coffer, H.F.

1961: **Hydraulic Fracture - Field Tests to Determine Areal Extent and Orientation.** As appeared in Journal of Petroleum Technology. V. 13, N.4., April 1961. p. 371-376.

Outlines some of the tests conducted on a Southern U.S. series of wells to determine fracture orientation.

Schulster, C.L.

1980: **Massive Hydraulic Fracture Mapping.** "Tar Sands Permeability Enhancement Workshop", Albequerque, New Mexico. p. 147-156.

Summarizes both surface and borehole monitoring techniques e.g. the development of the Borehole Seismic System and Borehole Hydrophone System. These sytems can be deployed in boreholes and used to monitor seismic activities. The surface electric potential system and surface voltmeter array are also discussed.

Srajer, V. and Barron, K.

1978: **Gas Observations in the Saline Creek Tunnel.** Energy Research Program, Mining Research Lab Division Report ERP/MRL 78/22 (OP). Canmet.

Results of gas sample analysis performed air injection tests to investigate degree of fracture permeability. (Detailed information).

Srajer, V.

1981: **Gas Monitoring Trial at the Gulf AOSTRA Surmont Lease.** Mining Research Lab Division Report ERP/MRL 81/60 (TR).

During Gulfs drilling program at Surmont, gas desorption tests were conducted to suggest gas levels expected in mining trials.

Srajer, V.

1980: **Air Injection Test in Oil Sands.** Mining Research Laboratories Report ERP/MRL 80-24 (OP). Canmet.

Report of injection tests done on Saline Creek tunnel.

Srajer, V. and Barron, K.

1977: **The Saline Creek Diversion Tunnel Fort McMurray, Alberta - The Gas Observations - Part 1.** Mining Research Lab Report. ERP/MRL 77-86 (TR). Canmet.

Short report on gas levels recorded during tunnelling.

Wong, A. and McCormack, M.

1985: **Operating Experiences with Bottomhole Instrumentation at AOSTRA Pilots.** Heavy Oil and Oil Sands Techn. Symposium Proc. Challenges and Innovations 1985, U of C, Alberta, February 20, 1985.

Provides an overview of bottomhole pressure and temperature monitoring systems at selected in situ steam assisted pilot projects. These systems would be useful for monitoring the recovery processes, production indices, pump performance, fluid movements and generally maintaining well integrity. Relevant to the actual production more so than monitoring permeability.

Wood, M.D., Holzhausen, G., Smith, C., Porter, S., Bachman, W. and Khaw, M.

1980: **A System for Mapping and Monitoring Subsurface Processes in Enhancing Recovery Schemes.** Chapter 48 of "The Future of Heavy Crude and Tar Sands". p. 442-454.

Describes a system that can be used to monitor and map a variety of subsurface structure and procedures related to enhanced recovery of tar sands. It is based on geophysical measurements of deformation by a complex processing procedure.

Wood, M.D., and Holzhausen, G.R.

1980: **Frac-Map Process Monitoring; Asphalt Ridge, Vernal, Utah.** Proceedings of Workshop on "Tar Sands Permeability Enhancement", Albequerque, New Mexico. p. 157-166.

Describes a monitoring system designed to measure the strike, dip, and areal extent of hydraulically induced fractures from deformation changes at ground surface. Explains the general concept and why this method has advantages over wellbore methods; provides an indication of overall geometry. Experiment was conducted in a tar sand at a depth of 118 to 160 meters.

Monitoring/Drilling - Secondary

Agar, J.G., Morgenstern, N.R., and Scott, J.D.

1983: **Geotechnical Testing of Alberta Oil Sands at Elevated Temperatures and Pressures.** Presented at 24th U.S. Symposium on Rock Mechanics.

Discusses testing methods of tar sands at elevated temperatures and pressures (in lab) and methods of obtaining undisturbed samples by coring when frozen.

Srajer, V.

The Saline Creek Diversion Tunnel Gas Observations. Part I; Prepared by Mining Research Laboratories, Canmet, June 1977. Report ERP/MRL 77-86 (TR).

Srajer, V.

1977: **The Saline Creek Diversion Tunnel.** Fort McMurray, Alberta. Part 2 - Hydrocarbon and Gas Analyses. Mining Research Lab Report ERP/MRL 77-119 (TR).

Hydraulic Mining - Primary

Gates, E.M. and Gilpen, R.R.

1978: **Jet Cutting of Oil Sands.** AOSTRA Seminar on Underground Excavation in Oil Sands. Edmonton, Alberta. May, 1978.

Short paper discusses proposed lab experiments to get scaling information for field trials. Pertinent but not much information.

Gates, E.M. and Gilpen, R.R.

1982: **Down-Hole Jet Piercing of Oil Sands.** Presented at 33rd Annual Techn. Mtg, CIMM, Calgary. June, 1982.

A study on using high pressure water jets to increase the effective diameter of a well bore was done using lab and field tests. Tests were inconclusive due to lack of ability to predict the diameter achieved.

Gates, E.M. and Toogood, R.W.

Post 1982: **A Model for Jet Piercing of Oilsands.** ASME paper #84-pet-17. Energy and Sources Tech. Conference. New Orleans. February, 1984.

Based on lab investigations and measurements a cutting model was developed to predict jet piercing rates and maximum depth of penetration. Paper appears to be of limited value.

Gates, E.M., Toogood, R.W., and Sinams, B.W.

1984: **A Model for Drilling by High Pressure Water Jets.** Presented at Seventh International Symposium on Jet Cutting Technology.

The report proposes that water jets are pulsed and not continuous so that modelling of their effectiveness should examine the probabilistic nature of the pressure excluding the failure criteria of the material.

Gilpen, R.R. and Gates, E.M.

1981: **Jet Piercing of Oil Sands.** Transactions of ASME, v. 103, p. 330-335, Journal of Energy Resources Technology.

Describes the results of an experimental investigation of oil sands by continuous and pulsed high-pressure water jets based on both laboratory and field tests. Relevant to the hydraulic mining scenario discussed for this study.

Gilpen, R.R., Gates, E.M. and Chau, W.T.R.

1980: **Jet Cutting of Oil Sands.** Presented at Fifth International Symposium on Jet Cutting Technology.

Project report of lab and field investigations that had the objective of finding lab criterial that would allow predicting water volumes and pressures for field extraction of tarsands.

Srajer, V.

1981: **The Investigation of Specific Cutting Resistance Values for Canstar Oil Sands Projects.** Prepared by Mining Research Laboratories for Canmet. May, 1981.

Wagner, C.G. and Hadges, E.L.

1984: **Downhole Hydraulic Mining System.** As presented to California Tar Sands Development Corp., Orange, CA.

Discusses a downhole hydraulic mining system that could be applicable to this study and also covers the basic tool design.

Hydraulic Fracturing - Primary

Bawden, W.F.

1981: **Hydraulic Fracturing in Alberta Tar Sand Formations - A Unique Material for In Situ Stress Management.** For the Workshop on Hydraulic Fracturing Stress Measurements, Monterey, CA.

Discussion of the in situ processes and the related stress fractures in Tar Sands and how they affect each other. Problems are outlined with the main ones resulting from lack of understanding of material and applicability of current rock mechanics theories to tar sand material.

Dusseault, M.B.

The Behaviour of Hydraulically Induced Fractures in Oil Sands. As appeared in Underground Rock Engineering, CIMM, special V.22, 1980. p. 36-41.

Presents a geomechanical model of hydraulic fracturing in oil sands. Outlines why conventional fracture mechanics are not applicable in the tar sands. The sands are essentially cohensionless with planes of parting acting as a fracture. The differences in material homogeneity within the McMurray formation preclude widespread predicability of fractures and control of fracturing is difficult.

Raisebeck, J.M. and Currie, J.B.

1981: **A Laboratory Investigation of Hydraulic Fracturing in Oil Sands.** In Situ, V.5, N.1., 1981. P. 1-24.

Settari, A. and Raisebeck, J.M.

1978: **Fracture Mechanics Analysis in In Situ Oil Sands Recovery.** Presented at the 29th Annual Technical meeting of the Petroleum Society of CIM. Paper # 78-29-18.

Reviews some of the factors which contribute to fracture initiation, development and orientation and pursues the idea of applying the elastic theory of fracturing to unconsolidated sands. Also identifies the variables which are most important to the fracturing processes. Mainly based on computer modelling.

Hydraulic Fracturing - Secondary

Fahy, J. and Marchart, L.C.

1980: **Tar Sand Permeability Enhancement.** Proceedings from Tar Sands Permeability Enhancement Workshop Albequerque, New Mexico. p. 9-16.

Fox, R.L.

1980: **Enhanced Oil Recovery Through Steam Drive and Permeability Enhancement.** Proceedings from Tar Sands Permeability Enhancement Workshop, Albequerque, New Mexico.

Blasting Primary

Cuderman, J.F.

1984: **High Energy Gas Fracturing Development, Final Report.** Prepared for Gas Research Institute Con. # 5080 - 321-0434

190 page document describing in detail the test set-ups, theory, math and equipment used in a series of tests of fracturing via propellants. Direct application to permeability enhancement in boreholes.

Cuderman, J.F.

1981: **Design and Modelling of Small Scale Multiple Fracturing Experiments.** Prepared by Sandia National Lab. for U.S. Department of Energy, Con # DE-AC04-76DP00789.

Cuderman, J.F.

1982: **Multiple Fracturing Experiments - Propellant and Borehole Considerations.** Presented at SPE/DOE Unconventional Gas Recovery Symposium, Pittsburg, PA.

Cuderman, J.F. and Northrop, D.A.

1984: **A Propellant - Based Technology for Multiple Fracturing Wellbores to Enhance Gas Recovery: Application and Results in Devonian Shales.** Presented at SPE/DOE/GRI Unconventional Gas Recovery Symposium, Pittsburgh, PA.

Cuderman, J.F. and Northrop, D.A.

1984: **High Energy Gas Fracturing - A New Technique for Enhanced Gas Recovery.** Presented by Sandia National Labs at AGA Operating Section Distribution/Transmission Conference, San Francisco, CA.

Cuderman, J.F.

1984: **Rock Mechanics Effects Observed Subsequent to Multiple Fracturing of Wellbores.** Presented to 25th U.S. Symposium on Rock Mechanics, Evanston, ILL.

Cuderman, C.F.

1984: **Application of a New Multiple Fracturing Technique to Enhance Gas Production in Devonian Shale.** Presented at International Gas Research Conference, Washington, D.C.

Doucet, R.

1984: **Drilling and Blasting in Tarsand.** Presented by Suncor Inc. Oil Sands Group. Blasting Seminar, San Diego, CA.

Review of Suncor's blasting practices. Interesting paper on blasting and highlights possible methane concerns.

Labor Canada.

1981: **Recommended Guidelines for Blasting.** Developed from Blasting Seminar. Hull, Quebec.

Outlines above relevance to Tar Sands. Quite vague but still very useful.

Plewes, H.D. Scott, J.D., and Hsu, T.R.

1985: **Dynamic Fracturing of Oil Sands.** Presented at "Heavy Oil and Oil Sands Technical Symposium"

Examines the use of explosives to dynamically generate horizontal fractures in intermediate and deep oil sand reservoirs utilizing model studies and lab experiments.

Ranney, L.

1984: **Horizontal Wells are all in Pay and Flow by Gravity.** Presented at 9th Annual Petroleum Conference, Robinson, Ill.

An old paper but discusses how effective a long horizontal hole is at fracturing sand with 250 feet of overburden by lifting the ground 1 1/2 inches.

Schamaun, J.T.

1980: **Enhancing Permeability in Oil Shale and Applications to Tar Sands.** Presented at Tar Sands Permeability Enhancement Workshop, Albequerque, New Mexico.

Mainly addresses permeability enhancement due to explosive rubbilization using chemical explosives. Unfortunately, it deals with oil shales at shallow depths. Some application to tar sands is mentioned.

Warpinski, N.R. and Cooper, P.W.

1980: **Enhanced Formation Permeability Through Tailored-Pulse Loading of Wellbore.** Presented at Tar Sands Permeability Workshop, Albequerque, New Mexico.

Describes a series of five full-scale tests performed to evaluate various multi-frac concepts in cased horizontal drillholes drilled in a tuft bed from a tunnel under 430 meters of overburden. An excellent reference. Very similar to what we are proposing.

Safety - Tertiary

Richmond, J.K., Sapko, M.J. and Miller, L. F.

Fire and Explosion Properties of Oil Shale. U.S. Department of the Interior, Bureau of Mines.

Covers a progress report on investigation into field and lab experiments of fire and explosion properties at Green River Oil Shale.

Associated Information - Primary

Butler, R.M.

1984: **Unpublished Text for Talk to Petroleum Society of CIM - "Some of the Main Challenges in the In Situ Recovery of Bitumen."** Presented to Petroleum Society of CIM, Calgary.

Discusses the key parameters of steam injection recovery processes. A good review of the state of this process knowledge and its key elements.

Associated Information - Secondary

Carigy, M.A., Kramers, J.W.

1973: **Guide to the Athabasca Oil Sands Area.** Prepared for the Canadian Society of Petroleum Geologists Oil Sand Symposium Edmonton, Alberta. 1973.

Excellent introduction to the geological characteristics of the Athabasca Tar Sands.

Pearson, M.

1983: **Cut-off Criteria for Mineable Oil Sands.** Presented to the Session on Oil Mining CIM District 5 Annual Meeting.

Qam, E.S., Edmunds, N.R. and Redford, D.A.

1984: **Methods of Enhancing Fluid Communication in Oil Sand.** Presented at SPE/DOE Fourth Symposium on Enhanced Oil Recovery, Tulsa, OK.

Generally outlines the range of permeability thickness for which hot water can be used as an enhancement agent and discusses the thermal flood method with injection of a solvent to reduce the viscosity of the bitumen.

Scott, J.D.

1982: **Application of Geotechnical Mechanics to Oil Sand In Situ Recovery Processes.**

Discusses geotechnical property changes as in situ sands are heated.

Associated Information - Tertiary

Butler, R.M.

1985: **In Situ Recovery Challenges of Bitumen.**

Is a general description of some of the problems faced and the advances made in solving these problems. More relevant to steam injection and in situ recovery.

Coates, R.

1984: **Physical Simulator for Horizontal Well.** Tar Sand Symposium Poc. U.S. Department of Energy. Vail, Co. Paper 3-2, 26-29, June 1984.

Describes a laboratory simulation of an in situ steam injection process using a scale reduced horizontal well implanted in an actual tar sand. May be relevant with regards to how each of the major sub-system physical properties were simulated and the data processing and software used.

Jenkins, G.R. and Kirkpatrick, J.W.

1979: **Twenty Years Operation of an In Situ Combustion Project.** Journal of Canadian Petroleum. V.18, N.1, Jan-Mar. 1979. P. 60-66.

Land, C.S., F.M. Carlson, and C.Q. Cupps.

1975: **Laboratory Investigation of Reverse Combustion in Two Utah Tar Sands.** Laramide Energy Research Centre. Lerc-R1-75, July 2, 1975.